

A computer-based auditory and visual sequential pattern test for school-aged children

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There is no happiness except in the realization that we have accomplished something.

Henry Ford

I certainly feel a great sense of accomplishment and delight now that I have completed this thesis and have finally come to the end of my studies. However, it would have been impossible without the help of a few people along the way.

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1.2 Abstract

Auditory processing refers to the efficiency and effectiveness by which the CNS utilises auditory information (ASHA, 2005). Auditory processing disorder (APD) is a processing dysfunction characterised by severe listening difficulties, despite normal peripheral hearing sensitivity. It affects approximately 3-5% of school aged children (Musiek & Chermak, 2007). An important step towards effective identification and treatment of these children is to develop improved methods of assessing listening skills and differentially diagnosing APD. A test that is commonly used internationally as part of a standard APD assessment is the Frequency Pattern Test (FPT). The FPT specifically targets temporal processing abilities related to the recall of a sequential pattern of a series of auditory stimuli. However, interpretation of this test is complicated by the multiple listening and cognitive skills involved, and by factors that may negatively affect test performance such as fatigue, motivation and attention. These factors are particularly relevant when testing children.

In order to establish APD as an auditory specific deficit rather than the auditory manifestation of a more global amodal or multimodal processing or cognitive deficit, some researchers (Cacace & McFarland, 2005) propose the incorporation of multimodal testing into standard clinical APD assessments. It has been suggested that comparisons on analogous auditory and visual tasks, for example, may hold implications for the differential diagnosis of processing deficits involving the central nervous system. However, there is a paucity of evidence regarding the clinical utility of visual analogs of central auditory tests in the differential diagnosis of central auditory processing deficits.

We have developed a new computer-based auditory and visual sequential patterns test, the *Bird Song Game*, which uses engaging computer animations and an interactive touchscreen

interface, and have collected data from typically developing school-aged children and children with APD.

A total of 128 children aged 6-10 years were recruited from two independent mainstream schools of differing decile rating; and a further 11 children with previously identified APD also participated. Analysis of results included comparisons between age, gender, left and right ears and schools. Further analysis compared results between the manual and verbal mode of reporting responses, as well as between the visual and auditory modalities.

Results demonstrate that scores attained by typically developing children on the *Bird Song Game* were similar to current normative scores on the traditional FPT. This indicates that the computer based version of the test is a good clinical substitute, and that the current normative values may be used in interpreting performance on the *Bird Song Game* in a clinical setting. There was a significant difference in performance on sequencing tasks in the auditory and visual modalities for both groups of children (three-way ANOVA, $p < 0.001$).

There was no significant difference in performance between the two reporting modes (manual and verbal) for either group (two-way ANOVA, $p < 0.05$). A significant difference in performance was found between the low and high decile school ($p < 0.001$) and an effect of musical education was seen in some groups

These findings provide evidence that a computer based interactive test offers an alternative procedure, and has several advantages over its CD based counterpart.

Table of Contents

1.1	ACKNOWLEDGEMENTS	III
1.2	ABSTRACT	V
	TABLE OF CONTENTS.....	VIII
1.3	LIST OF FIGURES.....	XI
1.4	LIST OF TABLES	XIII
1.5	LIST OF ABBREVIATIONS.....	XIV
1	INTRODUCTION	1
1.1	AUDITORY PROCESSING DISORDERS	1
1.2	ETIOLOGY	2
1.3	CO-MORBIDITY OF APD WITH OTHER LEARNING DIFFICULTIES.....	4
1.4	ASSESSMENT OF APD	6
1.5	THE FREQUENCY PATTERN TEST	7
1.6	TEMPORAL PROCESSING AND LANGUAGE.....	8
1.7	PITCH PERCEPTION AND LANGUAGE	10
1.8	WORKING MEMORY	12
1.9	REPORTING MODE.....	15
1.10	MODALITY SPECIFICITY.....	16
1.11	THE UNIVERSITY OF CANTERBURY <i>BIRD SONG GAME</i>	19
1.12	STATEMENT OF THE PROBLEM.....	21
1.12.1	Goal of the Study.....	21
1.12.2	Research Questions and Hypotheses.....	21
2	METHODOLOGY.....	23
2.1	PARTICIPANTS.....	23
2.1.1	Study A: Mainstream School children	23
2.1.2	Study B: Children previously diagnosed with APD	24
2.2	MUSICAL EXPERIENCE	25
2.3	PERIPHERAL AUDIOMETRIC ASSESSMENT	25
2.3.1	Equipment.....	25
2.3.2	Administration of peripheral auditory assessment.....	26

2.4	THE DESIGN OF THE UNIVERSITY OF CANTERBURY <i>BIRD SONG GAME</i>	26
2.5	<i>BIRD SONG GAME</i> TEST PROCEDURE	29
2.5.1	<i>Equipment</i>	29
2.5.2	<i>Calibration</i>	29
2.5.3	<i>The Bird Song Game Setup</i>	30
2.5.4	<i>Administration of the Bird Song Game</i>	30
2.5.5	<i>Study B – Children with APD</i>	34
2.6	ANALYSIS	35
3	RESULTS	36
3.1	PARTICIPANTS	36
3.2	COMPARISON BETWEEN GENDERS	37
3.3	COMPARISON BETWEEN SCHOOLS – AUDITORY MANUAL MODE	40
3.4	COMPARISON BETWEEN SCHOOLS – AUDITORY VERBAL MODE	42
3.5	COMPARISON BETWEEN EARS FOR AUDITORY MANUAL MODE	43
3.6	COMPARISON BETWEEN EARS FOR AUDITORY VERBAL MODE	45
3.7	COMPARISON BETWEEN AUDITORY MANUAL AND AUDITORY VERBAL RESPONSE MODE	46
3.8	RESPONSE TIME FOR AUDITORY MANUAL MODE	48
3.9	COMPARISON OF RESPONSE TIME BETWEEN ‘GOOD’ PERFORMERS AND ‘POOR’ PERFORMERS	49
3.10	COMPARISON BETWEEN SCHOOLS – VISUAL MODE	50
3.11	COMPARISONS TO PREVIOUSLY PUBLISHED NORMATIVE DATA	51
3.12	THE EFFECTS OF MUSICAL EXPERIENCE ON PERFORMANCE	53
3.13	APD GROUP PARTICIPANTS	54
3.14	COMPARISON OF SCORES BETWEEN GROUPS AND ACROSS STUDIES	57
4	DISCUSSION	59
4.1	EFFECT OF AGE AND GENDER ON AUDITORY SEQUENCING ABILITY	59
4.2	COMPARISON BETWEEN SCHOOLS OF DIFFERENT DECILE RATING	61
4.3	LEFT AND RIGHT EAR DIFFERENCES	63
4.4	MODE DIFFERENCES	65
4.5	RESPONSE TIME	66
4.6	MODALITY SPECIFICITY TASKS	67

4.7	COMPARISON TO NORMATIVE DATA	69
4.8	THE INFLUENCE OF MUSICAL EXPERIENCE.....	70
4.9	CHILDREN WITH APD.....	71
4.10	THEORETICAL AND CLINICAL IMPLICATIONS.....	73
4.11	LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH.....	75
	APPENDICES	78
<i>Appendix I:</i>	<i>Ethical Approval.....</i>	<i>78</i>
<i>Appendix II:</i>	<i>Project Information Sheet for Teachers.....</i>	<i>79</i>
<i>Appendix III:</i>	<i>School Participation Consent Form.....</i>	<i>83</i>
<i>Appendix V:</i>	<i>Project Information Sheet for Parents</i>	<i>85</i>
<i>Appendix VI:</i>	<i>Parent Consent Form</i>	<i>89</i>
<i>Appendix VII:</i>	<i>Hearing Test Results Summary.....</i>	<i>90</i>
4.12	REFERENCES	91

1.3 List of Figures

FIGURE 1: THE MULTI-COMPONENT WORKING MEMORY SYSTEM.	13
FIGURE 2: A SCREENSHOT OF THE ANIMATION USED FOR THE <i>BIRD SONG GAME</i>	28
FIGURE 3: SCHEMATIC REPRESENTATION OF THE TEST SET-UP FOR ADMINISTRATION OF THE <i>BIRD SONG GAME</i>	29
FIGURE 4: A SCREENSHOT OF THE SETUP PARAMETERS FOR THE <i>BIRD SONG GAME</i>	31
FIGURE 5: A SCREENSHOT OF THE PARTICIPANT INFORMATION SCREEN FOR THE <i>BIRD SONG GAME</i>	32
FIGURE 6: COMPARISON OF SCORES FOR THE DIFFERENT MODES OF TESTING	37
FIGURE 7: COMPARISON BETWEEN THE TWO MAINSTREAM SCHOOLS FOR THE AUDITORY MANUAL MODE DATA	41
FIGURE 8: COMPARISON BETWEEN THE TWO MAINSTREAM SCHOOLS FOR THE AUDITORY MANUAL MODE DATA	42
FIGURE 9: COMPARISON BETWEEN EARS FOR THE AUDITORY MANUAL MODE.	44
FIGURE 10: COMPARISON BETWEEN EARS FOR THE AUDITORY VERBAL MODE.	46
FIGURE 11: COMPARISON BETWEEN AUDITORY MANUAL AND AUDITORY VERBAL MODES FOR EACH AGE GROUP.	47
FIGURE 12: COMPARISON OF MEAN RESPONSE TIME (s) IN THE AUDITORY MANUAL MODE FOR RIGHT AND LEFT EARS.	49
FIGURE 13: COMPARISON OF RESPONSE TIME FOR GOOD AND POOR PERFORMERS.	50
FIGURE 14: COMPARISON OF VISUAL MANUAL AND VISUAL VERBAL SCORES BETWEEN THE MAINSTREAM SCHOOLS.	51
FIGURE 15: MEAN SCORE (AUDITORY MANUAL MODE ONLY) FOR PARTICIPANTS WITH AND WITHOUT MUSICAL EXPERIENCE IN EACH OF THE THREE AGE GROUPS FOR BOTH SCHOOLS.	53
FIGURE 16: SUMMARY OF THE NUMBER OF PARTICIPANTS WITH MUSICAL EXPERIENCE ACROSS EACH OF THE THREE AGE GROUPS FOR BOTH SCHOOLS	54

FIGURE 17: COMPARISON OF AUDITORY MANUAL AND AUDITORY VERBAL SCORES IN THE APD GROUP	56
FIGURE 18: A COMPARISON OF VISUAL MANUAL AND VISUAL VERBAL SCORES IN THE APD GROUP.	57
FIGURE 19: COMPARISON OF SCORES BETWEEN THE APD GROUP (APD), THE MAINSTREAM GROUP (MS), THE TYPICALLY DEVELOPING GROUP (TD) AND THE KELLY (2007) DATA.	58

1.4 List of Tables

TABLE 1: MAINSTREAM SCHOOL PARTICIPANTS.....	36
TABLE 2: APD GROUP PARTICIPANTS.....	36
TABLE 3: AUDITORY MANUAL MODE; ANALYSIS OF VARIANCE FOR THE EFFECTS OF SCHOOL, AGE AND GENDER ON THE DEPENDENT VARIABLE OF MEAN SCORE.	39
TABLE 4: AUDITORY VERBAL MODE: ANALYSIS OF VARIANCE FOR THE EFFECTS OF SCHOOL, AGE AND GENDER ON THE DEPENDENT VARIABLE OF MEAN SCORE.	40
TABLE 5: COMPARISON OF AUDITORY VERBAL RESULTS TO NORMATIVE DATA.	52
TABLE 6: TYPICALLY DEVELOPING (TD) CHILDREN IN THE 9-10 YEAR AGE GROUP FROM SCHOOL 1, COMPARED TO NORMATIVE DATA (KELLY, 2007).	53
TABLE 7: COMPARISON OF SCORES FOR THE FREQUENCY PATTERN TEST, THE <i>BIRD SONG GAME</i> - AUDITORY MANUAL MODE AND THE <i>BIRD SONG GAME</i> - VISUAL MANUAL MODE FOR ALL PARTICIPANTS IN THE APD GROUP. SCORES IN BOLD FONT ARE 'PASS' SCORES ACCORDING TO CURRENT NZ NORMATIVE DATA (KELLY, 2007); OTHERS ARE 'FAIL' SCORES.	55

1.5 List of Abbreviations

AM	Auditory Manual
APD	Auditory Processing Disorders
ASHA	American Speech Language Hearing Association
AV	Auditory Verbal
BSA	British Society of Audiology
CANS	Central auditory nervous system
FD	Frequency discrimination
FPT	Frequency Pattern Test
M	Mean
MLD	Masking level difference
OME	Otitis media with effusion
PSI	Paediatric Speech Intelligibility Test
RD	Reading disorders
REA	Right ear advantage
SEM	Standard error of the mean
SLI	Specific language impairment
SNR	Signal-to-noise ratio
SRD	Specific reading disorders
VM	Visual Manual
VV	Visual Verbal

Units

dB	Decibels
dB HL	Hearing level in decibels

dB SL Decibels sensation level

Hz Hertz

ms Milliseconds

1 Introduction

1.1 Auditory Processing Disorders

The process of comprehending a spoken message does not end with the simple detection of the acoustic stimulus itself. Indeed, there are multiple neurophysiological and cognitive processes that work in combination to enable an individual to decode and recognise speech (Musiek & Chermak, 2007). Auditory processing disorder (APD) is an auditory specific perceptual dysfunction that results when one or more of these processes are disrupted. The concept of an auditory processing disorder was first described in the 1950s by Myklebust (1954) and a team of Italian scientists (Bocca, Calearo, & Cassinari, 1954). Since that time however, ongoing debate regarding a clear operational definition of APD persists. As a result of this confusion, both the American Speech Language Hearing Association and the British Society of Audiology have independently convened multiple consensus groups in an effort to reach agreement on the problem of defining and diagnosing APD. Although no definitive consensus has yet been reached, we are closer to reaching a general accord than ever before. In line with position statements from both groups, APD is conceptualised as an auditory specific deficit in the recognition, discrimination, ordering, grouping and/or localisation of sounds that occurs in spite of normal peripheral hearing thresholds and normal intellectual capacity (ASHA, 2005; BSA, 2007).

Estimates from the US suggest that 3-5% of school-aged children are affected by APD (Chermak & Musiek, 2007) and there is no evidence to suggest that these numbers would differ significantly in the New Zealand population. If similar prevalence estimates apply in this country, it means that in a typical NZ classroom of 25 children, approximately one

child will present with severe listening difficulties, particularly when listening to speech in the presence of background or competing noise, despite having normal hearing sensitivity. These children may present with academic deficits such as reading difficulties, remembering instructions and staying focussed while listening (Bellis, 2003; Chermak & Musiek, 2007). Such difficulties may have a profound impact on a child's classroom learning and social development.

1.2 **Etiology**

In a small number of cases, APD may be the result of a neurological disorder, a genetic disorder, a neuromorphological abnormality or maturational delay (Bellis, 2003). However, in the majority of cases the cause of APD remains largely unknown (Bellis, 2003). A common putative cause for APD in children that is more readily identified is a significant past history of otitis media with effusion (OME). Several studies have shown that children with a history of persistent OME can develop abnormal binaural hearing processes (Hogan, Meyer, & Moore, 1996; Moore, Hartley, & Hogan, 2003; Moore, Hutchings, & Meyer, 1991; Pillsbury, Grose, & Hall, 1991). In two independent but similar studies Pillsbury et al. (1991) and Moore et al. (1991) demonstrated that children with a past history of chronic OME had poor binaural hearing as measured by masking level differences (MLD). MLD is a measure of binaural hearing that assesses a listener's ability to improve the detection of a tone in competing background noise. Chronic OME causes a disruption in the temporal aspects of sound transmission to the two sides of the brain, leading to the abnormal development of binaural hearing processes such as speech discrimination in competing background noise (Hartley & Moore, 2003). As outlined above, listening to speech in the presence of background noise is a task that is particularly difficult for children with APD. It is significant to note that in both studies the binaural

deficit was present even when the ears were healthy and hearing was within normal limits, suggesting that the deficit was the result of a disruption in central auditory processing.

Another measure that assesses a child's ability to process speech in noise is the Paediatric Speech Intelligibility Test (PSI). Gravel, Wallace & Ruben (1996) employed this test to assess 4 year old children with and without a significant history of OME in their first year of life. Results revealed that children with an early history of OME required a greater signal to noise ratio (SNR) in order to correctly identify 50% of PSI sentence items compared to the children with no history of OME. A subset of these children was also evaluated at 9 years of age, and no difference was found between the two groups on performance on the PSI. These results suggest although OME may cause auditory processing difficulties in early life, brain plasticity results in a gradual return to normal functioning following resolution of the OME and subsequent sensory deprivation in the central auditory system.

A longitudinal study undertaken by Hall et al. (1995) involved 22 children with a history of OME. These children were evaluated at 3 months and at 1 year after the insertion of ventilation tubes. Annual tests of MLD's were also obtained on a subset of these children at 2, 3 and 4 years after middle ear surgery. The authors found that even 2 years after surgery the OME group showed a significant deficit in binaural processing when compared to the control group with no history of OME. This indicates that although the restoration of consistent auditory input does result in the establishment of good binaural hearing, this process may take several years. During this time the effects of APD may have significant long-term consequences on a child's learning and language development.

In contrast to these findings, other studies have demonstrated that prolonged periods of OME have no significant effect on a range of developmental outcome measures such as cognitive, language, speech, literacy, auditory processing or psychosocial development (Paradise et al., 2003; Paradise et al., 2007; Zumach, Gerrits, Chenault, & Anteunis, 2010). Paradise et al. (2003; 2007) undertook a longitudinal study that compared the effects of prompt insertion or delayed insertion of ventilation tubes, in children with persistent OME. The children were randomly assigned to one of these two conditions and underwent a comprehensive battery of tests that assessed the outcome measures previously described, at 3, 4, 6 and 9-11 years of age. Results indicated that scores on developmental outcome measures did not differ significantly between the two treatment groups. This suggests that if left untreated, OME does not influence the development of speech and language, reading, cognitive abilities or psychosocial skills. Auditory processing abilities were assessed specifically using the children's version of the Hearing in Noise Test, but again no significant difference between treatment groups was found. Thus although a history of OME may be a contributing factor in some individual cases of APD, longitudinal studies suggest that a history of OME alone is neither necessary nor sufficient to account for auditory processing difficulties in children.

1.3 Co-morbidity of APD with other learning difficulties

One of the major difficulties encountered when assessing children suspected of APD is the significant co-occurrence of APD and other developmental disorders such as dyslexia, specific language impairment (SLI), reading disorders (RD) (King, Lombardino, Crandell, & Leonard, 2003; Sharma, Purdy, & Kelly, 2009; Wible, Nicol, & Kraus, 2005) and attention deficit hyperactivity disorder (ADHD) (Chermak, Somers, & Seikel, 1998). These other

disorders share many similar presenting features with APD, making it clinically challenging to discriminate between them.

To further complicate the issue of co-morbidity, disagreement exists around the degree to which some of these disorders do in fact coexist with APD. As an example, in one study it has been found that children with SLI exhibited normal performance on auditory tasks (Bishop, Carlyon, Deeks, & Bishop, 1999) suggesting that in this population of children, auditory deficits neither coexisted nor caused SLI. The variation in findings across studies may result from the use of psychophysical measures of auditory performance that were insufficiently sensitive to detect an underlying dysfunction, or may reflect the fact that deficits in language abilities were more subtle than could be detected by the assessments used.

The lack of agreement regarding co-morbidity has led to much research in this area, but few studies have used a range of auditory processing measures to specifically assess children with reading or language problems (Bishop, et al., 1999; King, et al., 2003). Of these, only King et al. (2003) used tests recommended for APD diagnosis by the ASHA Task Force on Central Auditory Processing Consensus Development (ASHA, 2005). In order to address this issue, Sharma et al. (2009) undertook a study that evaluated a wide range of auditory, language, and reading skills in a group of 68 children aged 7-12 years of age. The aim of the study was to establish the percentage of children with APD who have coexisting language and/or reading disorders. Auditory processing abilities were assessed using tests currently recommended by ASHA (2005) including the Dichotic Digit Test, Frequency Pattern Test, Random Gap Detection Test, compressed and reverberant CVC words and Masking Level Difference. Cognition, language, reading and phonological

abilities were also evaluated. The authors found that almost half of the children (47%) had co-occurring APD, SLI and RD, whereas only 4% had a 'pure' APD. The authors concluded that SLI and RD commonly co-occur with APD, making the diagnosis of APD challenging, since many of the same presenting behaviours are a feature of other conditions.

Whether APD causes or is a result of other neurological or sensory disorders, or whether co-existing difficulties like SLI and SRD result from a common underlying cause, is currently unclear (Moore, Halliday, & Amity, 2009). As a result, it is generally considered necessary to undertake a comprehensive assessment across a range of areas in order to identify children with APD and/or other co-morbid conditions and to manage them accordingly (ASHA, 2005).

1.4 Assessment of APD

The presenting symptoms and severity of APD differ significantly among individuals; therefore a number of different tests are needed to facilitate the identification of a given child's specific deficits. The current standard test battery consists of a series of listening tasks that a child must perform under controlled acoustic conditions, each presumed to assess a different underlying auditory processing skill. Many of the tests were originally designed to assess adults but have subsequently been applied to the paediatric population. As a consequence, Moore (2006) argues that there is a serious lack of good and scientifically sound validation for the use of these tests on this population of individuals.

Moreover, the majority of these tests are repetitive and non-engaging and when applied to the paediatric population, the non-interactive nature of the tests, their non-adaptive

design, the lack of meaningful feedback or reward for participants, combined with the length of time it typically takes to perform a full assessment (up to 3 hours) can mean that the results are tainted by fatigue, wavering attention and lack of motivation.

1.5 The Frequency Pattern Test

One of the tests commonly used as part of this test battery is the Frequency Pattern Test (FPT) (Musiek & Chermak, 1994). The test requires participants to listen to 40 or more sets of tone triads (in 6 possible patterns), consisting of a combination of low (880 Hz) and high (1122 Hz) frequency tones. Each tone is 150 ms in duration, separated by a 200 ms interval. The test is presented monaurally at 50 dB SL re 1000 Hz pure tone threshold. Participants are required to verbalise their response in the correct sequence in order to score a correct answer. A reversal of the pattern is considered to be an incorrect response.

Research has shown that the ability to properly sequence auditory information can be affected by a number of variables, including subject training/conditioning, type of stimuli, number of stimuli, duration of stimuli and rate and manner of stimulus presentation. (Thompson, Cranford, & Hoyer, 1999)

To perform well on the FPT, a listener needs to be able to discriminate between high and low frequency pure tones, a task that requires good spectral resolution. The sequence of tones must then be stored in a listener's short term memory before the sequence is verbally reported with the use of appropriate linguistic labels. This process relies on temporal processing and sequencing skills, a well developed concept of pitch, and adequate language skills. In addition, a high level of concentration, motivation and focused attention on the task is required (Jerger & Musiek, 2000). If these factors are not

controlled they may influence the results to such an extent that an incorrect diagnosis of APD may be made.

Normative data in the NZ population have been established (Kelly, 2007) but interpretation of a 'fail' on the FPT is complicated by the multitude of different processes required to perform this task. Each of these processes will be discussed in more detail below.

1.6 Temporal Processing and Language

The ability to correctly sequence a series of acoustic stimuli is indicative of functioning temporal processing abilities. Temporal processing refers to the processing of acoustic stimuli over time (Musiek et al., 2005). It facilitates language acquisition, prosody perception in speech, voice recognition, environmental sound recognition and melody and harmony perception in music (Tramo, Cariani, Koh, Makris, & Braida, 2005). Hence it is reasonable to assume that temporal processing deficits may result in delays in a child's speech, language and reading skills.

According to Medwetsky (2006) an understanding of how individuals perceive and process spoken language involves a complex intertwining of auditory processing, cognition and language. Initially the acoustic stimulus containing both temporal and frequency information is transformed into its neuroelectrical representation via the cochlea before it is transmitted to the auditory branch of the vestibulocochlear (VIIIth) cranial nerve and subsequently to the central auditory nervous system (CANS). Within the CANS the signals undergo a number of refinements whereby frequency, intensity and phase information is extracted. These extracted neuroelectrical patterns are maintained faithfully throughout all levels of the CANS and are ultimately relayed to both

hemispheres of the cortex. At this point the extracted signal interacts with the top down processes of attention, memory and language to enable the individual to understand speech. By conceptualising language processing in this way it is easy to conceptualise how a deficit in temporal processing that occurs at any stage, from the cochlea to the cortex, may affect an individual's ability to listen to and comprehend a spoken message. This task is made increasingly difficult in a classroom setting, where there is the added challenge of competing background noise.

Impairments in temporal processing have been implicated in the aforementioned co-morbid learning disorders (Farmer & Klein, 1995; Tallal, 1980; Walker, Shinn, Cranford, Givens, & Holbert, 2002). Temporal processing deficits are thought to be a primary cause of APD by some researchers (Jerger, 1998; Tallal, 2004; Wible, Nicol, & Kraus, 2002; Wible, et al., 2005). A deficit in temporal processing is thought to affect the development of reading and language skills by disrupting the normal acquisition of phonological sound awareness, critical for associating letter and letter combinations with their phonological equivalent (Reed, 1989; Tallal, 1980; Vellutino & Scanlon, 1987). Tallal (1980) suggests these phonological awareness deficits result from an inability to discriminate the temporal order of brief linguistic events that occur over a very short time frame (10's of milliseconds). For example, during speech, the rapid successive acoustic changes that occur during brief formant transitions in syllables such as /ba/ and /da/ are difficult for children with temporal processing deficits to detect. Children with SLI have been found to need a greater frequency difference in the vowel formants to identify syllables as different (McArthur & Bishop, 2004) and a longer interstimulus interval to identify tones (Tallal & Piercy, 1975). In addition, children with APD have been shown to require a wider

band of frequencies present in the speech signal in order to understand that signal (Heidtke, 2010). When a speech signal is degraded, some of the more robust frequency cues are removed or diminished, and the listener may be more dependent on subtle formant transition cues for consonant recognition. Temporal processing difficulties may therefore result in a greater reliance on a robust acoustic signal for speech understanding (Pichora-Fuller & Souza, 2003).

1.7 Pitch Perception and Language

The ability to detect pitch and pitch differences can have a profound impact on an individual's capacity to understand speech, and is dependent on both temporal and frequency coding (Javel & Mott, 1988). Tramo et al (2005) have demonstrated the critical role that the auditory cortex plays in our ability to perceive pitch. Using patients and animals with bilateral and unilateral auditory cortex lesions they were able to demonstrate that frequency selective neurons in both the left and right primary auditory cortex (A1) contribute to pitch change detection and pitch direction discrimination. They also found that these processes occur in separate areas of the cortex. This is consistent with other findings where Blood Oxygen Level Dependent responses were used to detect areas of A1 activated during a pitch detection task. Patterson and colleagues (Patterson, Uppenkamp, Johnsrude, & Griffiths, 2002) used this technique to show that lateral Heschl's gyrus responded to pitch, whereas changes in pitch were detected in more anterior regions of A1. A lesion or abnormality in the area of the auditory cortex is therefore highly likely to impair an individual's ability to perceive pitch.

Developmental factors must also be taken into account when considering pitch perception. Pitch discrimination requires the maturation of peripheral and central

auditory neural structures and pathways as well as the development of higher level cognitive skills such as attention and short term memory (Werner, 1996). Our capability for frequency discrimination (FD) improves with age and appears to develop as a result of increasing experience (Jensen & Neff, 1993). Psychophysical studies have shown that FD thresholds are poorer in typically developing young children relative to adults and follow a long developmental course (Thompson, et al., 1999). Some reports suggest that FD abilities reach adult like levels by 8 years of age (Thompson, et al., 1999) while others suggest that these continue to improve beyond 12 years of age (Maxon & Hochberg, 1982).

Another factor that impacts positively on an individual's ability to detect a change in frequency is musical training. Researchers have hypothesised that if similar temporal processes underlie the perception of pitch in both language and music, then improved pitch perception in music, due to musical education, may extend to pitch perception in language. Consequently, musicians should perceive pitch deviations better than non-musicians not only in music, but also in language (Magne, Schön, & Besson, 2006). Indeed this does seem to hold true. In one study the above hypothesis was investigated among adults who had an average of 15 years musical experience (Schon, Magne, & Besson, 2004). The authors designed an experiment that directly compared pitch processing in music and language. This was done by individually presenting both musical and spoken phrases while increasing the frequency of the final notes, or the F0 of the final words, by a large ('strong incongruities') or a small ('weak incongruities') amount. They found that adult musicians detected variations of pitch in melodic phrases and variations of fundamental frequency in sentences better than non-musicians. A follow-on study was

carried out in 2006 (Magne, et al., 2006) which aimed to demonstrate this same effect on a group of 8 year old children. Using the same experimental design the researchers found similar results. That is, performance on the pitch detection task was higher for those children with musical backgrounds for both the music perception task and for the language perception task. Therefore, although music training improves pitch perception in music it seems to also have a beneficial influence on the perception of prosody in language.

To facilitate the evaluation of temporal processing ability in children suspected of APD the FPT is used. This test has become one of the most widely used clinical tests included in the typical APD test battery (ASHA, 2005; Emanuel, 2002). In addition to temporal processing abilities, however, performance on the FPT is also reliant on working memory and other non-auditory factors including attention, motivation, perception, decision processes, language ability and motor skills. The extent to which extra auditory factors such as these affect the outcome of auditory processing assessments has recently been the subject of much debate (Cacace & McFarland, 2009) and is discussed in more detail in section 1.10 (Modality Specificity).

1.8 Working Memory

The term 'working memory' refers to an individual's ability to store and manipulate information simultaneously (Baddeley, 1996). A functioning working memory is critical for auditory sequencing tasks such as the FPT since throughout this test an individual is required to hold a three-tone sequence within their working memory before verbally describing that sequence.

According to the most widely accepted model, working memory consists of a number of separate but interacting temporary memory systems (Baddeley, 1986; Baddeley & Hitch, 1974).

A current schema of working memory (Baddeley, 2003) is shown in Figure 1.

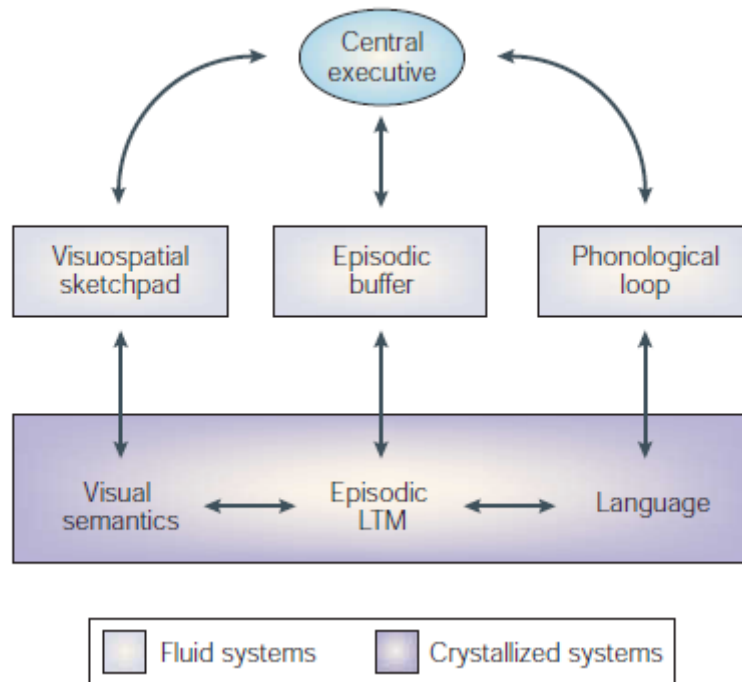


Figure 1: The multi-component working memory system.

The dark purple areas represent long term or crystallised knowledge. The lighter purple areas in the mid-level represent the three elements of working memory. The *episodic buffer* provides an interface between the sub systems of working memory and long-term memory (LTM) (Baddeley, 2003)

The *central executive* centre forms the basis of this model of working memory. It is suggested that this limited-capacity processing system is responsible for allocating the resources needed to support the processing and storage of incoming information. The functioning of working memory via the central executive system is heavily reliant on the frontal lobes of the brain (Baddeley, 1996).

The *phonological loop* is a temporary storage mechanism capable of storing limited amounts of phonological information. Baddeley et al. (1998) proposed that it evolved in order to facilitate the acquisition of language. Subsequently, weak phonological loop skills are associated with poor vocabulary acquisition, and severe impairments of the phonological loop may contribute to Specific Language Impairment – a disorder that has been identified to coexist with APD.

The second temporary storage mechanism in this schema is the *visuospatial sketchpad*, representing information in terms of its visuospatial features. Like the phonological loop, the visuospatial sketchpad is limited in capacity, typically to about three or four objects. The ability to hold and manipulate visuospatial representations provides a measure of non-verbal intelligence.

A third subcomponent of working memory in this model is the *episodic buffer*. It is suggested that the episodic buffer is responsible for integrating the systems responsible for temporary and long-term memory. The detailed structure of the episodic buffer and methods of assessing its capacity have yet to be described (Baddeley, 2000).

For participants with normal hearing, it is known that the immediate recall of auditory stimuli improves with age (Jutras & Gagne, 1999; Vuontela et al., 2003). The results of a study by Cacace & McFarland (1992) indicate that an ability to recall sequences consisting of pure tones increases from 6.7 tones for children between the ages of 7-10 to 9.7 tones for adults. This is consistent with improvements in temporal resolution (the ability to perceive changes in auditory stimuli over time) and auditory temporal integration (the ability to sum acoustic information over time to improve detection, recognition, and discrimination of stimuli) as a function of age. It is also consistent with the suggestion that

the ability to store information in working memory improves with age (Just & Carpenter, 1992). This maturational effect results in faster information processing and an increase in short term memory capacity allowing for improved performance in older children (Fry & Hale, 2000).

1.9 Reporting Mode

In the current version of the FPT an individual is required to apply a linguistic label to a sequence of acoustic stimuli and verbally report on this sequence. Musiek (2002) and Bellis (2003) suggest if an individual performs poorly on the FPT when asked to verbally report the sequence heard, they may be allowed to either hum the pattern or use their hands to manually indicate the sequence of high and low tones heard. The assumption is that allowing an individual to hum the pattern may result in an improved test score, compared to that obtained when using a verbal reporting mode. This, according to Musiek (2002) and Bellis (2003), is indicative of a difficulty in transferring information from the right to the left hemisphere (across the corpus callosum) or a problem accessing the left hemisphere - the primary language area of the brain in most individuals (Musiek & Pinheiro, 1987). A humming response is presumed to involve only the right hemisphere, and by deduction, if an individual is able to hum a test pattern but is unable to verbally describe it, the site of lesion in that individual is presumed to be in either the left, language dominant hemisphere or in the corpus callosum.

The Bellis/Ferre Model (Bellis & Ferre, 1999) attempts to relate the pattern of results on an APD assessment and other behavioural, cognitive, language and learning tests to an underlying neurophysiologic basis. This allows for the categorisation of APD into various subtypes, which has implications for management and intervention strategies. However,

this model remains a theoretical construct, and the validity of making assumptions about the site of lesion in children with APD based on their pattern of results on tests like the FPT is not universally accepted.

1.10 **Modality Specificity**

As outlined above, diagnosis of APD is complicated by the involvement of multiple listening and higher order processing skills required to perform a given task in the APD test battery. Hence performance on a task is the product of multiple factors such as perception, attention, motivation, language abilities, decision processes and motor skills. The extent to which these extra-auditory factors influence performance on APD tests is currently a major source of controversy in the field of audiology (McFarland & Cacace, 2009).

Various researchers argue that the unimodal framework currently used to identify APD provides sufficient evidence to diagnose an audition-specific dysfunction (Katz & Tillery, 2005; Musiek, Bellis, & Chermak, 2005). In contrast however, McFarland & Cacace (2009) advocate a modality specific approach to testing. They suggest that the use of auditory only testing, although necessary, does not distinguish cognitive, language-based and/or supra-modal attentional problems from APD. As an alternative they propose the incorporation of multimodal testing into an APD assessment in order to establish an auditory specific deficit that is not influenced by these other factors. One way this can be achieved is by systematically varying the nature of a stimulus while holding all other factors constant. As an example, discrimination performance on an auditory frequency pattern task may be compared to discrimination performance on a visual colour pattern task (Cacace, McFarland, Emrich, & Haller, 1992). If poor performance is due to an

auditory-specific process, then the deficit seen on the auditory task would be greater than that seen when other sensory modalities are used. Thus dissociation between performances on analogous versions of a task using different stimulus modalities can be established.

However, there are some difficulties with this approach. Some argue that it is not within the scope of practice for audiologists to administer tests in a different sensory modality such as the visual modality (Musiek, Bellis, et al., 2005) . Others argue that there is no need to include multimodal testing within the APD battery since it is possible to diagnose APD on the basis of intra-test and inter-test comparisons within the existing test battery (Katz & Tillery, 2005). Musiek et al. (2005) also contend that APD can be diagnosed using the current APD battery simply by demonstrating distinctive patterns of test performance across multidisciplinary tests.

In addition, there are complexities involved in designing completely analogous tasks in different modalities. It is difficult to design a task that compares performance on analogous auditory and visual tasks and to be certain that they are measuring similar processing mechanisms (Krutsch & McKeever, 1990; Voyer & Boudreau, 2003). Although the concept of multimodal testing has been used extensively in the fields of philosophy, psychology, medicine and neural science, its use is not well established in the field of audiology. Hence, there is a paucity of evidence regarding the clinical utility of visual analogues used to differentially diagnose APD. One example that has been used is the dichotic visual test which is purportedly equivalent to the dichotic digits test. In a study by Bellis, Billiet & Ross (2008) these two tests were administered to children with normal hearing, vision, cognition and language and no evidence of APD. The results suggest that

the visual task was more difficult than the auditory task for these children due to the extra processing resources required for the transfer of the visual input into verbal output. Clearly this indicates that the visual and auditory versions of the dichotic digits test were not entirely analogous with respect to the complexity of cortical processing.

The degree to which the auditory cortex is modality specific is also a topic of much debate. In an attempt to map the auditory cortex, Poremba et al. (2003) measured the glucose uptake in the intact hemisphere and the acoustically isolated contralateral hemisphere of a rhesus monkey. They concluded that both the visual and auditory regions were modality specific and that the auditory cortex was responsible for analyzing acoustic stimuli to facilitate the identification and recognition of the incoming stimulus. This supports the concept of a modality specific auditory cortex. However an alternative view has been suggested by other researchers. Sams et al. (1991) demonstrated that neuronal activity in the primary auditory cortex is modified by visual input. In addition, Calvert (1997) found that areas formerly thought to be sensitive only to auditory stimuli can be activated during visual-only tasks. These studies, in contrast to those of Poremba et al. (2003), suggest that the auditory cortex is not auditory specific but rather its activity is subject to modification by other cortical regions. If this is indeed the case it would not be neurophysiologically possible to demonstrate an exclusive auditory specific deficit as advocated by McFarland & Cacace (Cacace & McFarland, 2005, 2009) .

In conclusion, when a child presents to an audiologist for auditory processing assessment, it is generally because that child is experiencing significant listening difficulties in real world situations. Regardless of whether these difficulties are caused by an auditory deficit, are a result of more global processing issues, or coexist with other learning

problems, the child and their parents need some help managing the presenting difficulties. Ultimately it is the responsibility of the audiologist to diagnose, with as much accuracy as is possible within the limitations of the currently available test battery, the specific deficit, and to offer intervention and management strategies to allay the difficulties the child is experiencing. In future years assessment of APD may include multi-modality testing, but until such time as these tests have been rigorously tested and validated a multidisciplinary approach to diagnosis and management is the preferred clinical approach.

1.11 **The University of Canterbury *Bird Song Game***

The complex nature of APD means that diagnosing the disorder as distinct from other co-morbid and similarly presenting disorders is challenging. To facilitate diagnosis, a battery of tests is used to identify APD. The tests themselves are repetitive, non-engaging and prolonged. As a result it is frequently difficult to classify poor performance as a true APD or rather as resulting from fatigue, wavering attention or a lack of motivation. This can lead to misclassification or over diagnosis of children with APD (Silman, Silverman, & Emmer, 2000).

With this in mind we have identified several issues with the current version of the FPT.

These include:

- i. Failing to engage a child or provide motivation for the task at hand;
- ii. The lack of a conditioning step to ensure individuals understand the concept of pitch and can discriminate between the two different pitch stimuli;
- iii. A failure to provide information regarding the modality specificity of a temporal sequencing deficit.

In order to address these issues, a new computer-based, interactive touch screen version of the FPT (the *Birdsong Game*) has been designed. Due to the extensive use of computers in the current educational environment, it is expected the children will be comfortable with this format of testing. It is also envisaged that the interactive nature of the test will be engaging and motivating for children undergoing assessment.

In addition, by incorporating a conditioning step in the test procedure, participants are given the opportunity to familiarise themselves with the type of stimuli and the contrast between the stimuli. They are also made aware of what is required of them during the testing. This gives the investigator the confidence that the individual has mastered the concept of pitch, is capable of recognising the difference in pitch between the two stimuli and can verbally describe this difference. Such a conditioning phase is not standard in the current version of the test.

As discussed above, the modality specific nature of an individual's deficits is not routinely assessed in the current APD test battery. In an attempt to address this issue a new test procedure using a visual sequential pattern task has been included in the *Bird Song Game*.

A better understanding of the modality specificity of APD may lead to an improved understanding of a child's deficits, and may therefore guide management and intervention strategies.

A major advantage of using a computer-based test is that it enables the accurate measurement of parameters such as response time, which is not possible using the current CD based version of the test. In addition, previous studies have shown that children diagnosed with APD show improved performance on auditory sequencing tasks if there is greater contrast or complexity of the auditory stimuli (Tallal et al., 1996).

Manipulation of the stimulus parameters is easily achieved with this newly developed computer software and will be the subject of future studies. Furthermore, the computer-based format provides for rapid and efficient data collection and analysis, and eliminates errors in scoring the test.

1.12 **Statement of the Problem**

1.12.1 **Goal of the Study**

The primary aim of this study was to use a computerised version of the Frequency Pattern Test (the *Bird Song Game*) to assess the auditory sequencing abilities of school aged children in New Zealand.

In addition to this the *Bird Song Game* was designed to:

- i. Be engaging, to help maintain a child's attention and interest during testing;
- ii. Include a conditioning step to ensure children have an adequate concept of, and vocabulary to describe, pitch;
- iii. Provide information about the modality specificity of a processing deficit.

The present investigation will assess a tool that will have immediate clinical application, but more importantly, will serve as a platform through which the precise nature of auditory processing deficits in children may be better understood.

1.12.2 **Research Questions and Hypotheses**

Specifically, this study aims to:

- 1) Determine whether the percentage correct scores obtained using the *Bird Song Game* are consistent with those obtained using the traditional, CD-based version of the FPT.

- 2) Establish whether there is a difference in performance, in children with or without APD, on sequencing tasks in the auditory and visual modalities. *It is hypothesised that performance on an auditory sequencing task will be significantly poorer than on a visual sequencing task in both groups.*
- 3) Determine whether there is a difference in performance, in children with or without APD, between the manual and verbal reporting modes utilised in the *Bird Song Game*. *It is hypothesised that there will be no significant difference between manual and verbal reporting modes.*
- 4) Determine whether there is a difference in performance on the *Bird Song Game* software between participants from schools with different socioeconomic ratings. *It is hypothesised that performance will be significantly higher for children from a higher socioeconomic area.*
- 5) Assess the relationship between musical education and performance on an auditory sequencing task. *It is hypothesised that performance will be significantly higher for children with musical education compared to children with no musical education.*

2 Methodology

Ethical approval for the present study was obtained from University of Canterbury Human Ethics Committee, reference HEC 2010/24.

2.1 Participants

2.1.1 Study A: Mainstream School children

A total of 128 participants were recruited from two individual schools within the Christchurch area. This group consisted of 59 males and 69 females between the ages of 6-10 years. Two schools of differing decile rating were asked to participate in the study – School 1 (decile 9) and School 2 (decile 4). Consent to participate was obtained in the first instance from the Principals of each participating school. Classrooms of children of appropriate age were identified by the Principals and an information pack was sent home to the parents of every child in these classes to invite them to participate in the study. This inclusive approach was used to ensure all children within a classroom had equal opportunity to participate in the study and thereby undergo hearing screening free of charge, an important consideration for a school-based study such as this. The information packs contained detailed information sheets outlining the purpose and procedures of the project, as well as a parent consent form.

Inclusion criteria

All participants: (i) were aged 6 – 10 years; (ii) used English as their first language; (iii) had no peripheral hearing loss, i.e. a pure-tone average of ≤ 20 dB HL (500 Hz, 1000Hz, 2000 Hz and 4000 Hz); and (iv) had Type A tympanograms bilaterally.

Those children who failed to meet the inclusion criteria were referred appropriately for further investigation regarding their hearing but excluded from further participation in the study.

2.1.2 **Study B: Children previously diagnosed with APD**

Eleven children previously identified with auditory processing difficulties, based on current clinical protocols, were recruited from the University of Canterbury, Speech and Hearing Clinic. As for Study A, parents received an information pack containing detailed information sheets, and parent consent forms.

Inclusion criteria

All participants: (i) were aged 6 – 10 years; (ii) used English as their first language; (iii) had no peripheral hearing loss, i.e. a pure-tone average of ≤ 20 dB HL (500 Hz, 1000Hz, 2000 Hz and 4000 Hz); (iv) had Type A tympanograms bilaterally; and (v) had been previously diagnosed with APD.

Consent was obtained prior to the commencement of each assessment session, which for Study A, took place over a 30 minute period during the school day (9am-3pm) in a quiet room located within the child's school environment. For Study B the children were required to attend a session at the Speech and Hearing Clinic at the University of Canterbury.

All participating children received a small reward to acknowledge their participation in the research project. In Study B parents of the participants also received travel reimbursement.

2.2 Musical Experience

Included in all information packs was a question regarding the child's musical experience.

It was stated as follows:

“Does your child have good musical skills, take any formal music lessons, or is currently involved in any musical/dance activities? Please specify Y/N”

The consent form, including the answer to this musical experience question, was completed by a parent or caregiver prior to assessment.

2.3 Peripheral Audiometric Assessment

Peripheral audiometric assessment was carried out on all participants to determine their peripheral hearing status. While it is documented that APD may co-exist with peripheral hearing loss, an individual's performance on most tests of auditory processing is affected by hearing loss (Baran, 2007; Chermak & Musiek, 1997). Therefore normal peripheral hearing was used as an inclusion criterion in the current study. Furthermore, normative data available for the APD tests utilized in this study apply only to individuals with normal peripheral hearing (Kelly, 2007).

2.3.1 Equipment

For Study A, all testing was performed in a quiet room within each participating school.

For Study B, testing took place within a sound-proofed booth at the University of Canterbury, Speech and Hearing Clinic. An Interacoustics AS608 Screening Audiometer was used for pure tone audiometric assessment and a Interacoustics MT10 Portable Tympanometer was used for tympanometric assessments.

All equipment was calibrated within the previous 12 months by an authorised calibration service.

2.3.2 **Administration of peripheral auditory assessment**

Prior to administration of the *Bird Song Game*, otoscopy, puretone audiometry and tympanometry were all performed according to standard audiological test protocols (New Zealand Audiological Society (NZAS), 2007).

2.3.2.1 *Immittance Audiometry*

Following otoscopy each participants' tympanograms were recorded according to standard clinical procedures.

2.3.2.2 *Pure-tone Audiometry*

A standard screening procedure was used to determine participants' thresholds of hearing – down to a screening level of 20 dB HL – at 500, 1000, 2000, and 4000 Hz, using supra-aural headphones.

2.3.2.3 *Peripheral Testing Pass Criteria*

A participant was considered to have passed the peripheral hearing assessment if their pure-tone thresholds (at 500, 1000, 2000 and 4000 Hz) were ≤ 20 dB HL and tympanometry yielded normal type “A” tympanograms bilaterally.

2.4 **The Design of the University of Canterbury *Bird Song Game***

The *Bird Song Game* software is a computer-based auditory and visual sequential pattern test designed for use in school-aged children. It was designed to replicate the current CD based version of the FPT commonly used in APD assessments (Musiek, 1994), while providing an engaging, user-friendly interface that can be used in conjunction with an

external ELO ET1715K 17" touch screen monitor (Tyco Electronics Corp., USA) (Figure 2).

In addition, it allows for easy manipulation of stimulus parameters in order to establish which parameters have an impact on performance on a sequential auditory frequency pattern task.

The application was developed by Rickard & Rickard (2010) using Adobe Flash CS Professional (Adobe Systems Incorporated, USA) with ActionScript 3.0. Flash is a multimedia development platform used to create interactive vector graphic applications. The software was deployed as an Adobe Air 1.0 application allowing it to be run as a standalone, full screen desktop application.

The program controlled the presentation of auditory and visual stimuli and recorded participant responses and timing data. All data was written to the file system in an XML (Extensible Mark-up Language) file format. Raw data in the XML files was parsed into a MySQL database management system (version 5.1.41) to facilitate data extraction and analysis.

The test requires participants to listen to 20 sets of tone triads (6 possible combinations), consisting of a combination of low (880 Hz) and high (1122 Hz) frequency tones. Each tone is 150 ms in duration, separated by a 200 ms interval. The test is presented monaurally at 50 dB SL re 1000 Hz pure tone threshold.

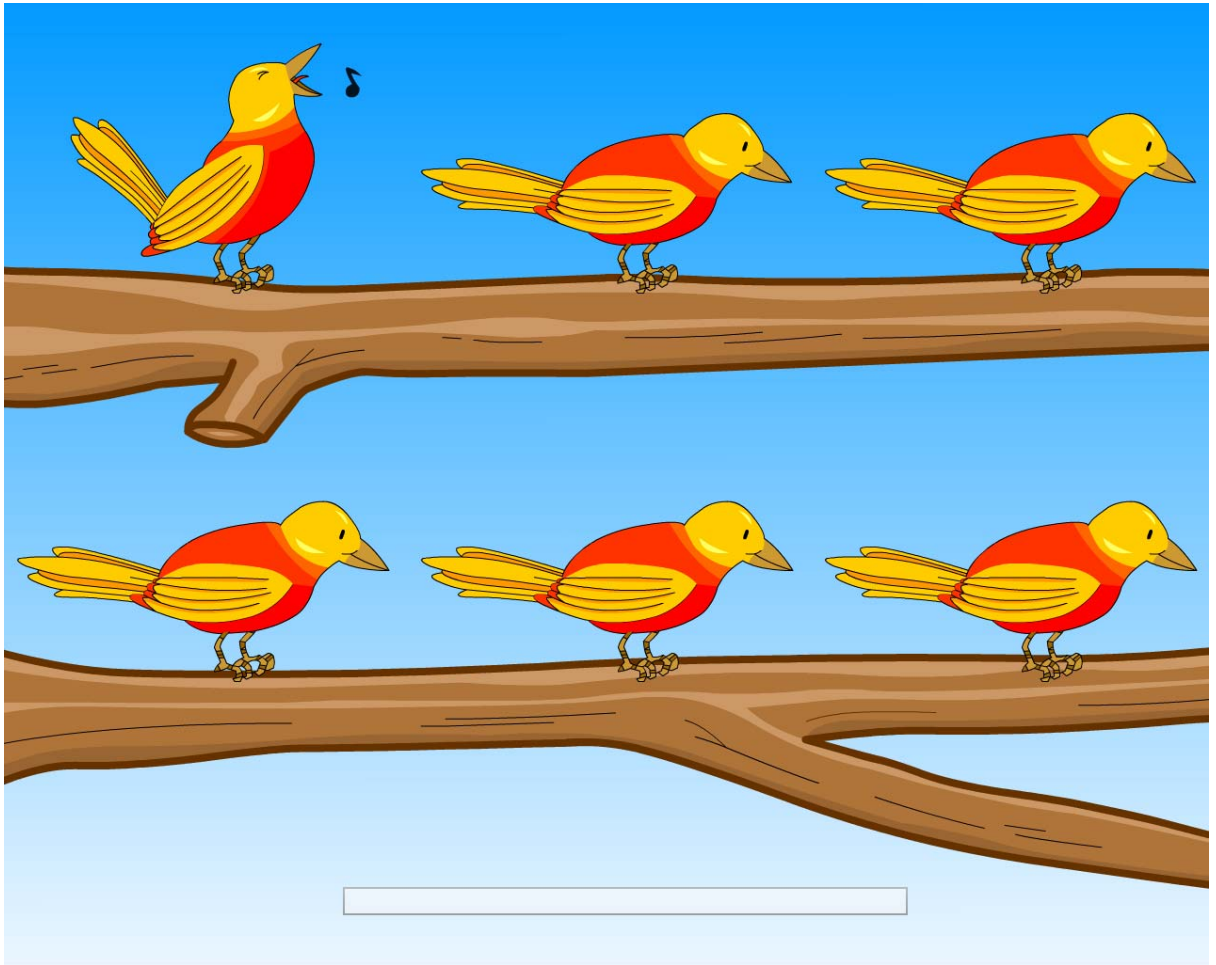


Figure 2: A screenshot of the animation used for the *Bird Song Game*

2.5 *Bird Song Game Test Procedure*

2.5.1 Equipment

The Bird Song Game was run on a Lenovo laptop computer and the pure-tone stimuli were presented via Sennheiser HD 215 supra-aural headphones driven by an InSync Buddy USB 6G sound-card attached to the laptop computer. An external ELO ET1715L 17" touchscreen monitor (Tyco Electronics Corp., USA), connected to the laptop was used to present the visual stimulus to the participants as shown in Figure 3.

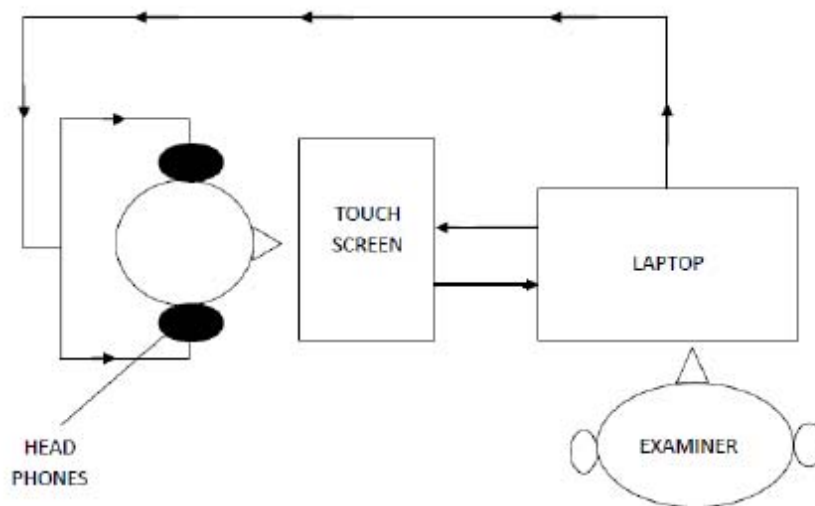


Figure 3: Schematic representation of the test set-up for administration of the *Bird Song Game*

2.5.2 Calibration

The Sennheiser HD215 headphones were placed on a Brüel & Kjær Type 4128 Head and Torso Simulator (HATS) connected to a Brüel & Kjær 7539 5/1-ch. Input/Output Controller Module. The sound pressure level of each pure tone stimulus (880 Hz and 1122 Hz) was

measured using the Brüel & Kjær PULSE 11.1 noise and vibration analysis platform, and was adjusted and set to 60 dB SPL.

2.5.3 The Bird Song Game Setup

For the administration of the *Bird Song Game* in this study the parameters were set as shown in Figure 4. Ear presentation order could be set to 'right then left', 'left then right' or 'random', as shown in Figure 4. The number of presentations per ear was set at 20 presentations, although the software allows the examiner to alter this. The pause between presentations was set at 2000 ms and a progress bar was displayed to give participants a gauge of their progress during test administration

Prior to the participants entering the testing room the examiner would enter their personal details in the information screen as shown below (Figure 5). As name and date of birth were entered into the text fields, a unique client identification number was automatically generated using a combination of parts of this information.

2.5.4 Administration of the *Bird Song Game*

The Bird Song Game software uses a touchscreen as the response interface. The primary investigator was seated at a laptop computer in a quiet room, and the participant was seated in front of a touch screen in the same room as the investigator. Participants were introduced to the *Bird Song Game* with an Instruction Screen. This allowed the participant to become familiar with the rate and intensity of presentation of the tones and the degree to which they needed to touch the touchscreen in order to register a response. It also allowed the primary investigator to establish the participant's ability to perceive the pitch differences between the high and low tones, and to be able describe this difference verbally.

Presentation Level: 60 dBHL

Ear Presentation Order: Random

Advancing Between Stimuli: Automatic

Number of Presentations per Ear: 20

Pause Between Presentations: 2000 milliseconds

Show Progress Bar: Yes

Saved File Directory: C:\BirdSong\Saved Files

Mode of Testing: Manual and Verbal

Restore Defaults

OK

Cancel

Figure 4: A screenshot of the setup parameters for the *Bird Song Game*

Client Details

Client Number:

First Name:

Last Name:

Date of Birth: Day: Month: Year:

Gender: ☒ Male ☐ Female

School:

Figure 5: A screenshot of the participant information screen for the *Bird Song Game*

The following instructions were given to each participant. *“Look at the screen. You can see three birds on the top branch and three birds on the bottom branch. I want you to touch the screen, listen to the sounds and tell me what you can hear”*. If the child indicates they can hear a difference the following question is asked: *“Can you describe the difference to me?”* Once the investigator is satisfied the participant is able to distinguish a difference between the two tones and is able to label the sounds appropriately, using their own descriptive vocabulary, they proceeded to the testing phase, outlined below:

- i) **Visual and Auditory mode:** This was a conditioning step, where the auditory stimuli (low (880Hz) and high (1122 Hz) frequency tones) were paired with simple visual animations. The birds were either at a low or high position on the screen, in order to reinforce the association between the frequency of a given tone and a screen position. Children were instructed to watch the birds and to listen to a simultaneous series of binaurally presented tonal triads. They were then required to repeat the combination of tones they heard manually, by touching the birds on the screen in the appropriate sequence.
- ii) **Auditory Manual (AM) mode:** Stimuli were presented to each ear separately with the starting ear being randomly assigned. This time, the participants heard a sequence of three tonal stimuli with no corresponding visual stimulus. They were requested to listen to the sequence and to manually respond by touching the images on the screen in the same sequence. They were rewarded with a visual stimulus only after making their response (touching the screen). A total of 20 presentations per ear (a mixture of the 6 possible combinations of tone triads) were made and the application automatically saved all response data to a file.

iii) **Auditory Verbal (AV) mode:** In this part of the test the stimuli were presented as above, but this time the participant was asked to refrain from touching the screen.

Instead, participants were instructed to verbally describe the sequence of tones they heard using their own descriptive vocabulary as established at the Instruction Screen.

The investigator then pressed the touchscreen in the sequence reported by the participant, and the data from 20 presentations per participant were collected as above.

This part of the test was designed to replicate the current administration procedures utilised in the FPT.

iv) **Visual Manual (VM) mode:** Participants receive visual stimuli only in this test, and were required to press the touchscreen in the correct sequence (after each of 20 presentations).

v) **Visual Verbal (VV) mode:** As in (iii) the participants were asked not to touch the screen, but to use their own vocabulary to describe the sequence of visual stimuli. The investigator pressed the touch screen in the sequence reported by the participant and the data from 20 presentations were collected.

Throughout application of the *Bird Song Game* the investigator provided verbal instructions and encouragement to the participant.

2.5.5 Study B – Children with APD

This part of the study was conducted at the University of Canterbury Speech and Hearing Clinic. Children previously diagnosed with APD by the Speech and Hearing Clinic underwent the same series of tests as outlined above for Study A: that is, a review of their hearing and tympanometry, and the 5 subtests of the *Bird Song Game*.

2.6 Analysis

Analysis (using Analysis of Variance) involved comparisons across age groups, gender, ears (left vs. right), verbal vs. manual response mode, level of musical experience, school decile rating and response modality (auditory and visual). In addition, response times and patterns were compared between those children who scored below 30% and those who scored above 70%, and between the children with previously diagnosed APD and the larger cohort of Mainstream School children. Results are presented as mean \pm standard deviation.

The data was also compared to New Zealand normative data for the current version of the Frequency Pattern Test (Kelly, 2007).

3 Results

3.1 Participants

A total of 185 children were screened for participation in this study. A total of 46 children were excluded from the study on the basis of failing one or both of the hearing screening criteria: hearing sensitivity worse than 20 dB HL at any frequency 0.5-4 kHz or a Type B tympanogram in either ear. The remaining 139 children participated further in the study and were assessed using the *Bird Song Game*. Table 1 summarises the demographics of the Mainstream School (MS) participant group (n=128); Table 2 summarises the 11 participants in the APD group.

Table 1: Mainstream School Participants

Age Group		
Girls	6	11
	7-8	27
	9-10	31
	<i>Total Girls</i>	69
Boys	6	8
	7-8	24
	9-10	27
	<i>Total Boys</i>	59
Total Participants		128

Table 2: APD Group Participants

Participant	Gender	Age
1	M	7.7
2	M	7.7
3	F	8.6
4	F	7.11
5	M	9.1
6	F	7.8
7	M	9.11
8	M	7.2
9	M	9.4
10	F	10.0
11	F	8.9
Average Age		8.6

3.2 Comparison between Genders

The *Bird Song Game* automatically collected data from individual participants and calculated the percentage of correct responses for each mode of testing.

An overview of the mean scores (%) for each age (left and right ear averaged) and school is shown in Figure 6 below. The graphs illustrate the differences between the two Mainstream Schools and the relationship between score and age for each gender. The Auditory Manual (AM) and Auditory Verbal (AV) mean scores are displayed on separate graphs.

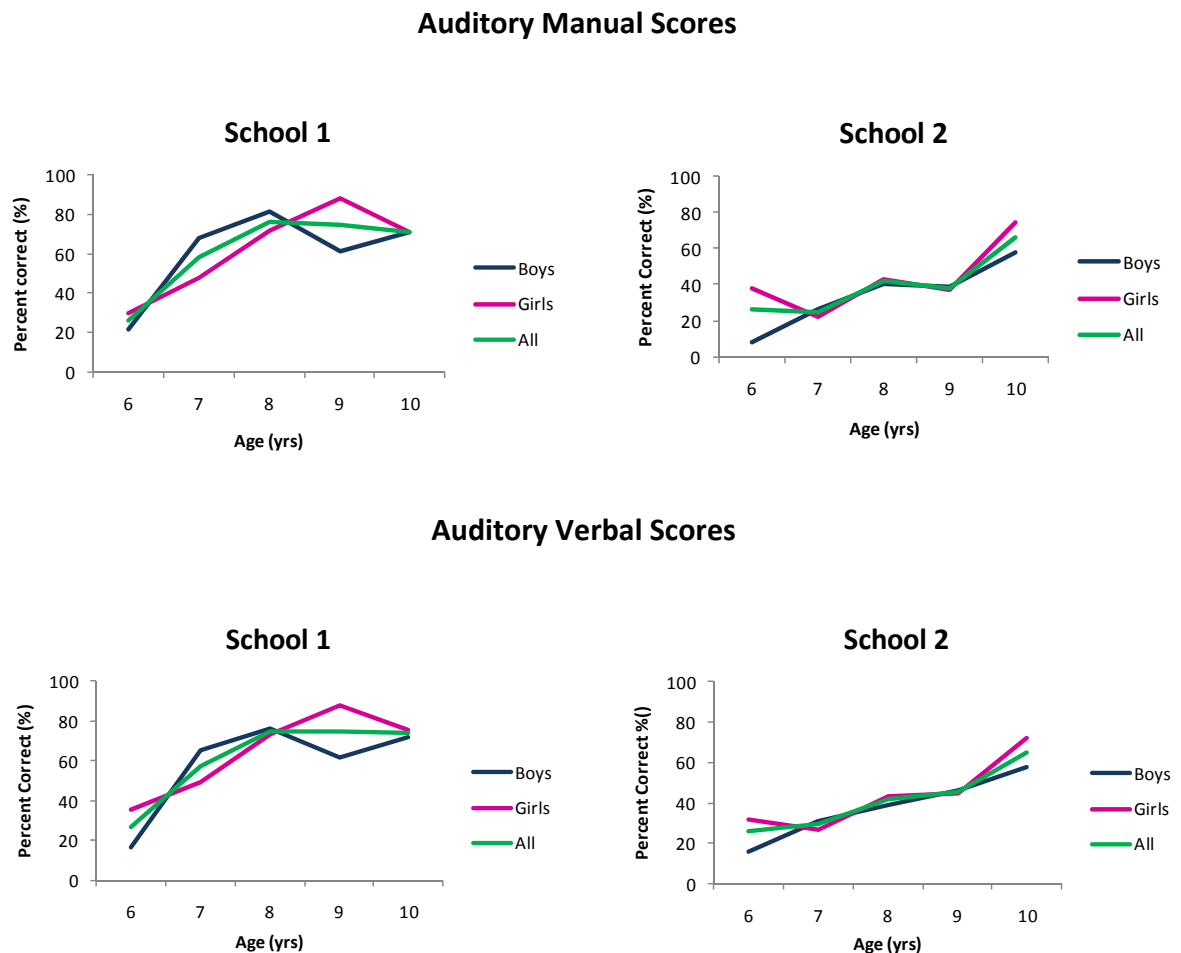


Figure 6: Comparison of scores for the different modes of testing

The graphs illustrate the scores of the different age groups and genders from each school. Individual results from each ear (left and right) have been pooled.

The graphs show a general improvement in mean score with increasing age in both the AM and AV modes. The pattern of relationship between percentage score and age is very similar for both modes of testing, and there is little difference between genders at any age or in either mode of testing. Between the ages of 7-9 years, participants from School 1 appear to out-perform their peers from School 2 in both the AM and AV modes.

However by the age of 10 years results between the two schools are similar.

Interestingly, there is little improvement in performance in either mode between the ages of 8-10 in School 1. However, this plateau is not replicated in the data from School 2, with an overall gradual improvement in scores for both genders with age, with a slight dip in the 9 yrs old age group's performance that recovers by the age of 10 yrs.

To analyse this data in more detail a three-way ANOVA was performed. Analysis showed no significant effect of gender in either mode, but a significant effect of both school and age (see Tables 3 and 4 for detail). The results for the AM mode are illustrated in Table 3, and for the AV mode, in Table 4.

Table 3: Auditory Manual Mode; Analysis of Variance for the effects of school, age and gender on the dependent variable of mean score.

df = degrees of freedom, F = the calculated F value and p = probability (n = 108).

Source of variation	Sum of squares	df	F	p
Main effects				
School	13048.96	1	17.38	<0.001
Age	22989.37	4	7.65	<0.001
Gender	550.59	1	0.73	0.394
2-way interactions				
School x Age	5798.93	4	1.93	0.112
School x Gender	369.28	1	0.49	0.485
Age x Gender	3115.29	4	1.04	0.393
3-way interactions				
School x Age x Gender	2012.25	4	0.67	0.615
Error	66078.10	88		

Table 4: Auditory Verbal Mode: Analysis of Variance for the effects of school, age and gender on the dependent variable of mean score.

df = degrees of freedom, F = the calculated F value and p = probability (n = 108).

Source of variation	Sum of squares	df	F	p
Main effects				
School	10508.54	1	15.37	<0.001
Age	22802.77	4	8.38	<0.001
Gender	838.12	1	1.23	0.271
2-way interactions				
School x Age	3807.40	4	1.39	0.243
School x Gender	0.00314	1	0.00000459	0.998
Age x Gender	2326.55	4	0.851	0.497
3-way interactions				
School x Age x Gender	1363.72	4	0.50	0.737
Error	60165.16	88		

3.3 Comparison between Schools – Auditory Manual mode

As a significant difference in mean scores was observed between the two schools, a further analysis was performed in order to investigate these differences in more detail. AM mode data from School 1 and School 2 are compared below. In this analysis the participants were grouped into three age groups: 6 yrs, 7-8 yrs, and 9-10 yrs. The mean scores for the right and left ear for the AM mode were analysed individually and the results are illustrated in Figure 7.

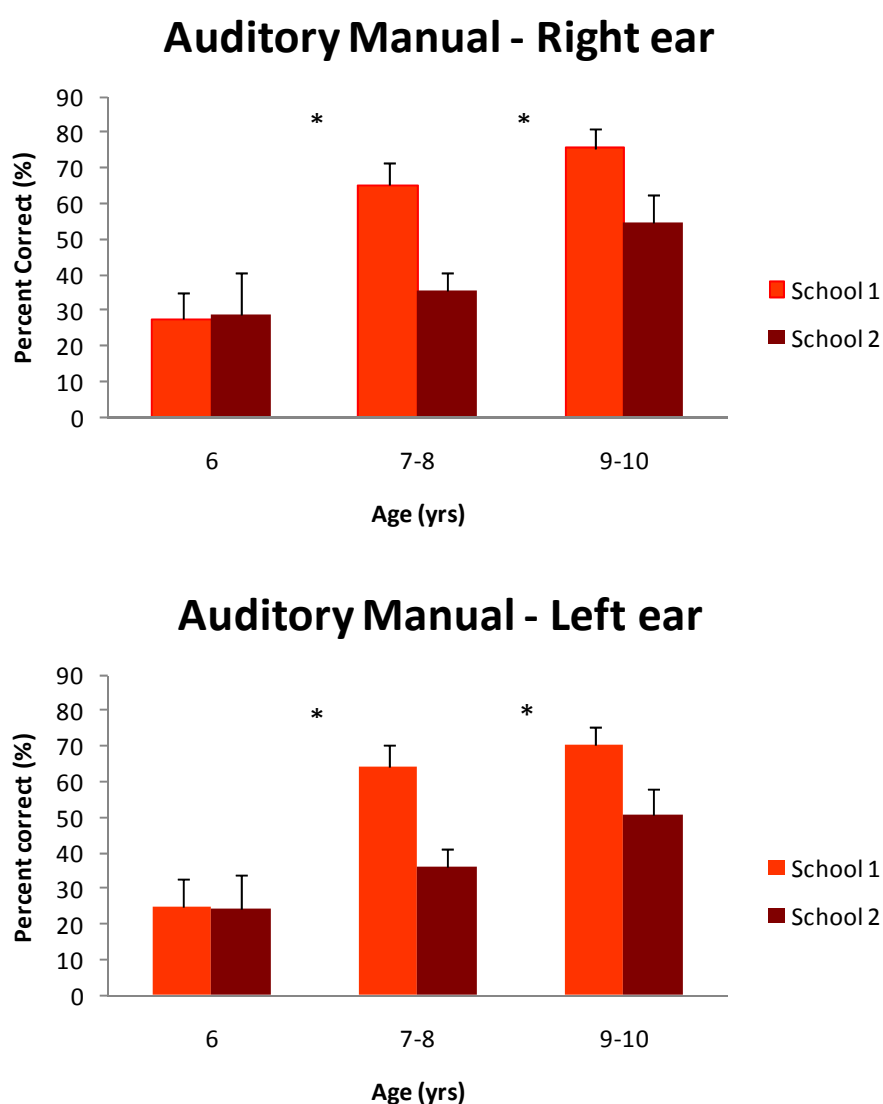


Figure 7: Comparison between the two Mainstream Schools for the Auditory Manual mode data
Right and left ears are analysed separately.

Post hoc pairwise multiple comparisons (Holm-Sidak Method) revealed some significant differences ($p < 0.05$). Notably there were significant differences between the two schools in both the 7-8 yr ($p < 0.001$) and 9-10 yr ($p = 0.035$) age group for the right ear; and the 7-8 yr ($p < 0.001$) and the 9-10 yr ($p = 0.023$) age groups for the left ear. In the 6 yr age group there was no significant difference between the two schools for either ear.

3.4 Comparison between Schools – Auditory Verbal mode

Auditory Verbal mode data from School 1 and School 2 are compared below. As for the above analysis the participants were grouped into 3 age groups (6 yrs, 7-8 yrs, and 9-10 yrs). The mean scores for the right and left ear for the AV mode were analysed individually and the results are illustrated in Figure 8.

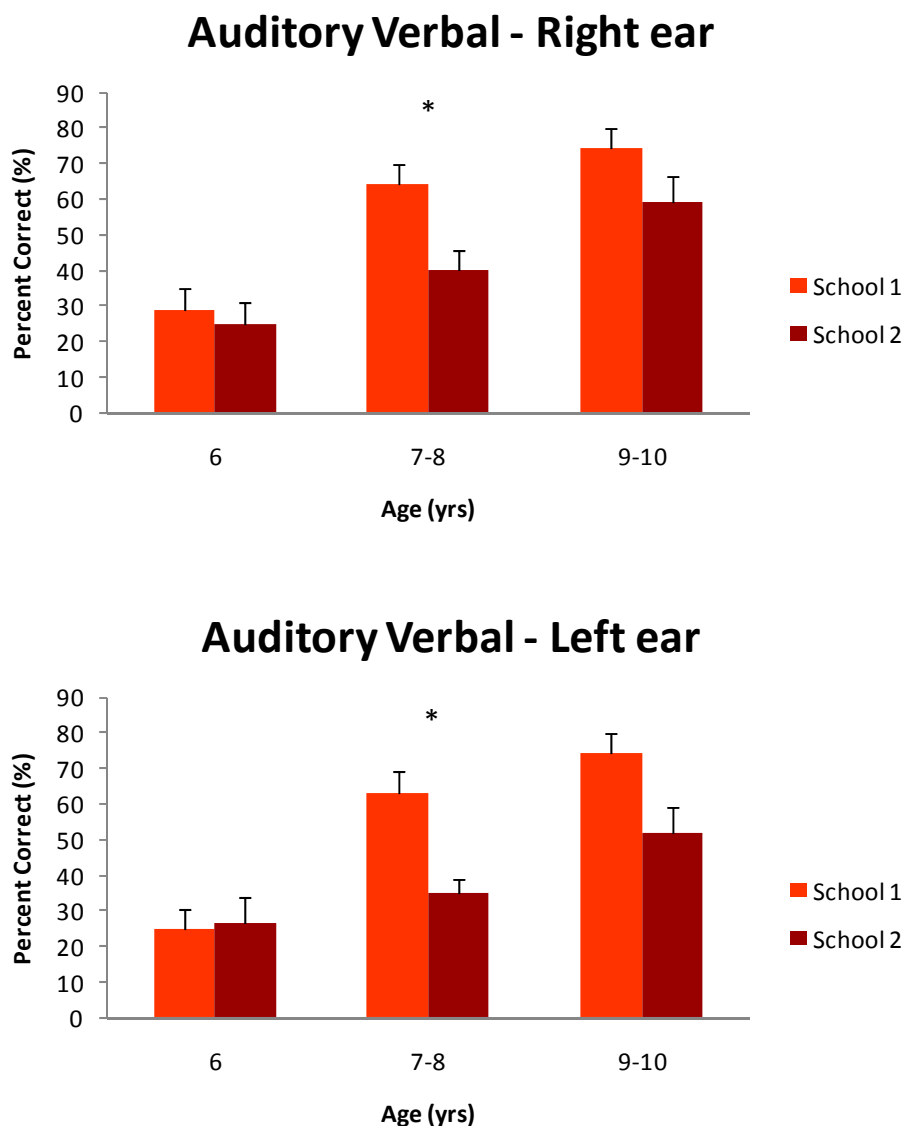


Figure 8: Comparison between the two Mainstream Schools for the Auditory Manual mode data
Right and left ears are analysed separately.

Post hoc pairwise multiple comparisons (using the Holm-Sidak Method) were performed and revealed some significant differences ($p < 0.05$). Notably there were significant differences between the two schools in the 7-8 yr ($p = 0.002$) age group in the right ear, and the 7-8 yr ($p = 0.001$) and 9-10 yr ($p = 0.001$) age groups in the left ear. Again there was no significant difference between the schools for either ear in the 6 yr age group.

3.5 Comparison between ears for Auditory Manual Mode

In order to investigate the presence or lack of a right ear advantage in the participant group a comparison between scores from each ear was undertaken. Figure 9 compares the right and left ear results for the AM mode. Since no gender effect was found in the previous analysis (see Section 3.2), results from boys and girls have been pooled. Results from the two schools are displayed on separate graphs. Figure 9 illustrates that there is a trend towards very slightly higher scores in the right ear compared to the left in most age groups from each school, but that this difference is not statistically significant.

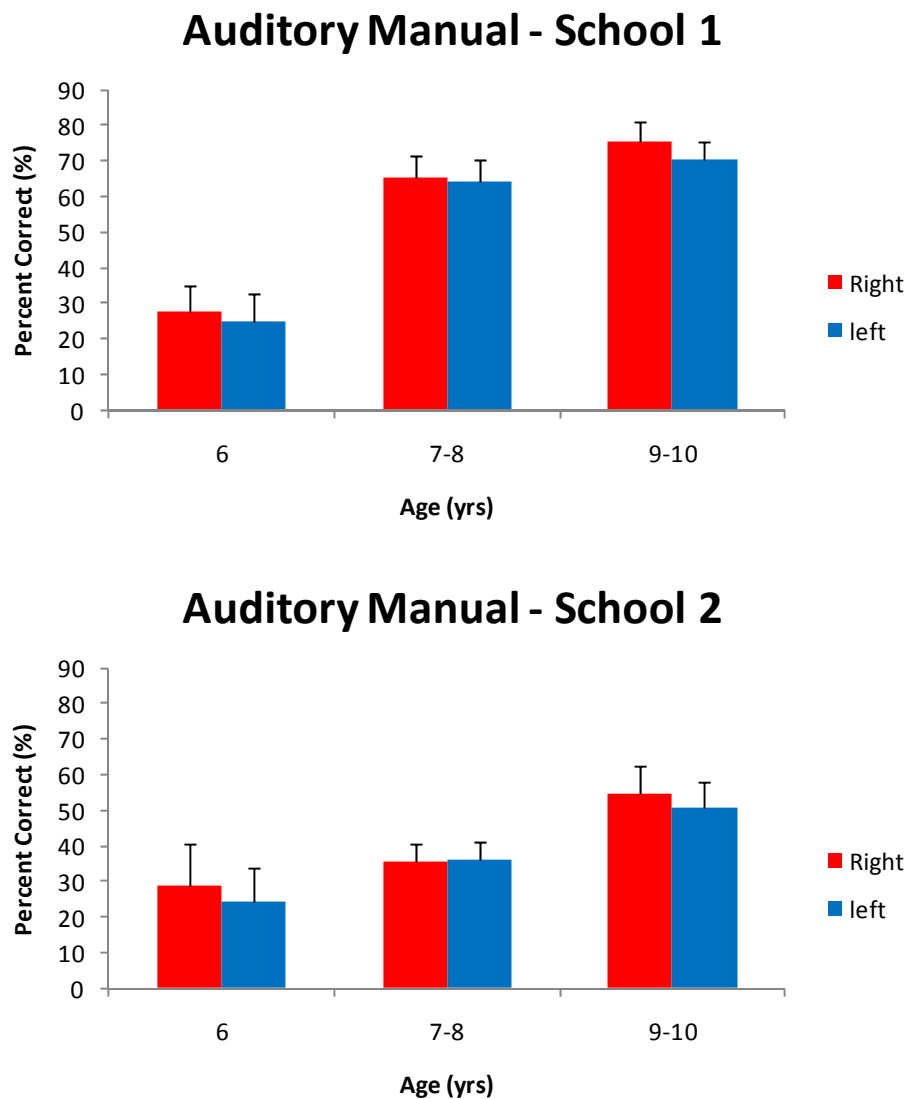


Figure 9: Comparison between ears for the Auditory Manual mode.

Both sets of results (School 1 and School 2) were analysed with a two-way ANOVA. This revealed a significant age effect [$F(2,148) = 16.916, p < 0.001$] between the three age groups in School 1. However, no ear effect was found [$F(1,148) = 0.208, p = 0.649$] and there was no statistically significant interaction between the age group scores and left and right ear scores ($p = 0.953$).

Similar results were found for School 2. Analysis revealed a significant age effect [$F(2, 96) = 5.507, p = 0.005$] between the three age groups. No ear effect was found [$F(1, 96) = 0.235, p = 0.629$] and there was no statistically significant interaction between the age group scores and left and right ear scores ($p = 0.960$).

3.6 Comparison between ears for Auditory Verbal Mode

Figure 10 compares the right and left ear results for the AV mode. Results from boys and girls have been pooled. Results from the two schools are displayed on separate graphs. This figure again illustrates that in most age groups participants tended to achieve a higher score when the stimuli were presented to the right ear, however any right ear advantage was minimal.

To further evaluate this slight difference, a two-way ANOVA was performed. For School 1 this revealed a significant age effect [$F(2, 108) = 20.532, p < 0.005$] across the three age groups. No ear effect was found [$F(1, 108) = 0.045, p = 0.832$] and there was no statistically significant interaction between the age group scores and left and right ear scores ($p = 0.946$). For School 2 there was a significant age effect [$F(2, 96) = 8.156, p < 0.001$] across the three age groups but again, no ear effect was found [$F(1, 96) = 0.355, p = 0.553$] and there was no statistically significant interaction between the age group scores and left and right ear scores ($p = 0.848$).

In summary, these comparisons (Figures 9 and 10) indicate the lack of a significant right ear advantage in any age group from either school for either response mode.

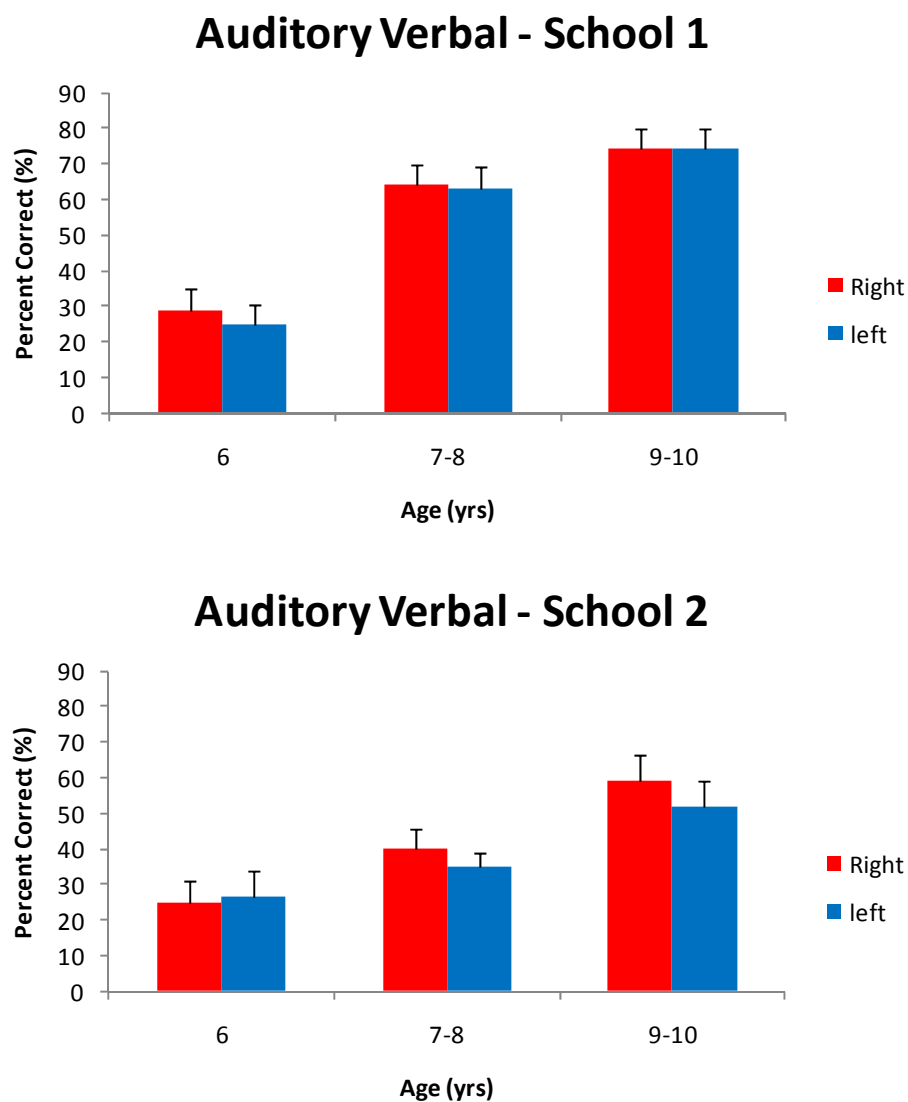


Figure 10: Comparison between ears for the Auditory Verbal Mode.

3.7 Comparison between Auditory Manual and Auditory Verbal response mode

To investigate whether or not performance differed between the manual and verbal reporting conditions a comparison of the AM and AV scores for each age group were evaluated. These results are graphically displayed in Figure 11. Since there was a significant difference in performance between the schools (see Section 3.3 and 3.4) results from School 1 and School 2 were evaluated separately.

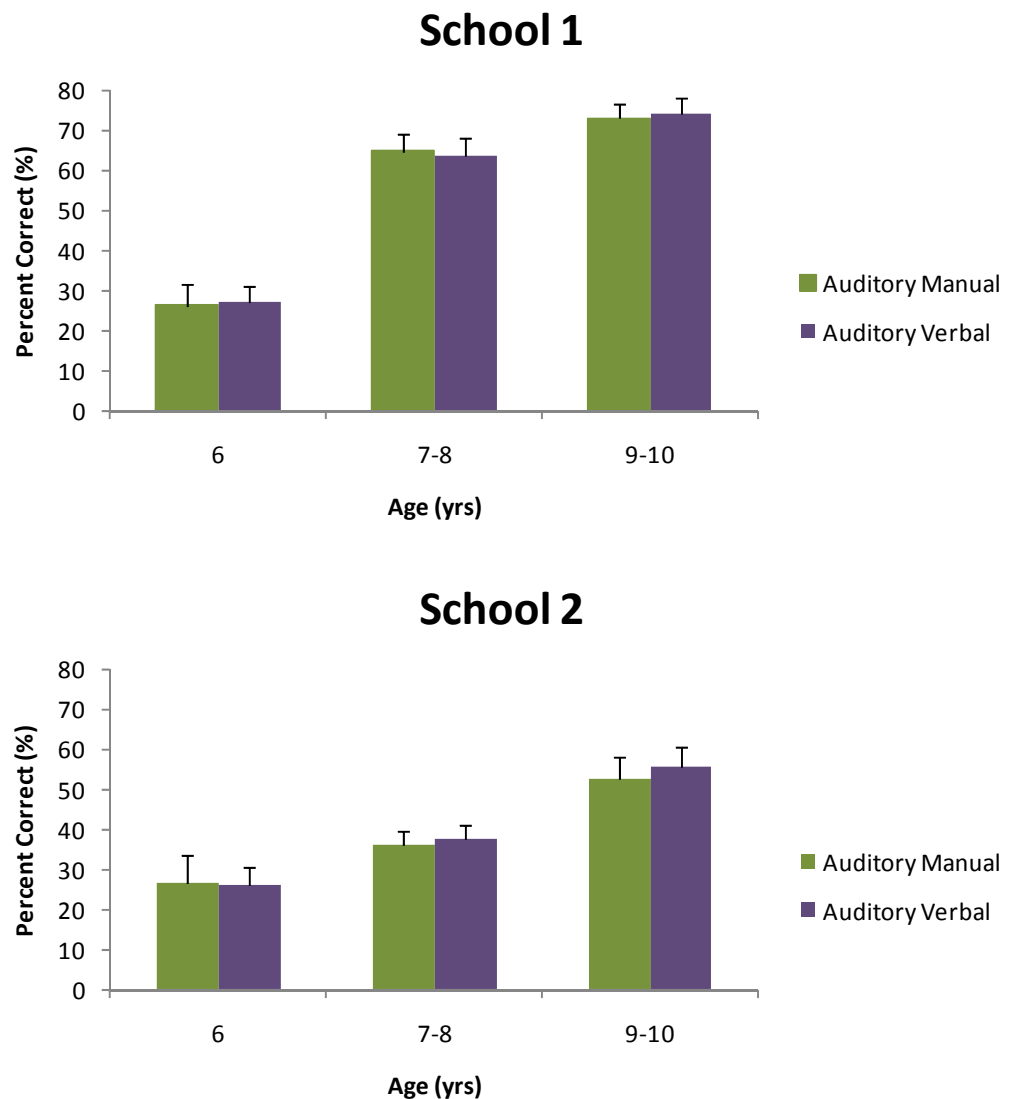


Figure 11: Comparison between Auditory Manual and Auditory Verbal modes for each age group.

Results were analysed with a two-way ANOVA. Analysis of School 1 data revealed a significant age effect [$F(2,302) = 37.624, p < 0.001$] across the three age groups. No effect of mode was found [$F(1,302) = 0.026, p = 0.872$] and there was no statistically significant interaction between the age group scores and the response mode ($p = 0.973$).

Post hoc pairwise multiple comparisons (using the Holm-Sidak Method) were performed and revealed some significant individual age group differences ($p < 0.05$). The scores for

the 6 yr olds were significantly different to those of the 7-8 yr ($p = 0.01$) and 9-10 yr ($p = 0.009$) groups in School 1.

No significant difference between the AM and AV scores were apparent for School 2 either. A two-way ANOVA revealed a significant age effect [$F(2,198) = 13.715, p < 0.001$] across the three age groups, but no effect of mode was found [$F(1,198) = 0.085, p = 0.771$]. As for School 1, there was no statistically significant interaction between the age group scores and the response mode for School 2 ($p = 0.956$).

Post hoc pairwise multiple comparisons (using the Holm-Sidak Method) revealed a significant difference between the 6 yr and 9-10 yr groups ($p = 0.017$) and the 7-8 yr and 9-10 yr groups ($p = 0.025$). Interestingly, scores for the 6 yr and 7-8 yr groups were not significantly different for School 2.

3.8 Response time for Auditory Manual mode

In order to evaluate ear effects in more detail, an analysis of response time was made using data from the 9-10 year old age group from School 1 (the largest cohort of participants in the study, $n = 39$). The average response time for the left and right ears are summarised in Figure 12. Note that the order of presentation to the two ears was randomised for each participant by the *Bird Song Game* software.

An independent-samples t-test was conducted to compare average response time in the right and left ears. There was no significant difference in the response time for the right ear ($M = 2.58 \pm 1.25$) and left ear ($M = 2.62 \pm 1.25$); $t(81) = 1.71, p = 0.948$.

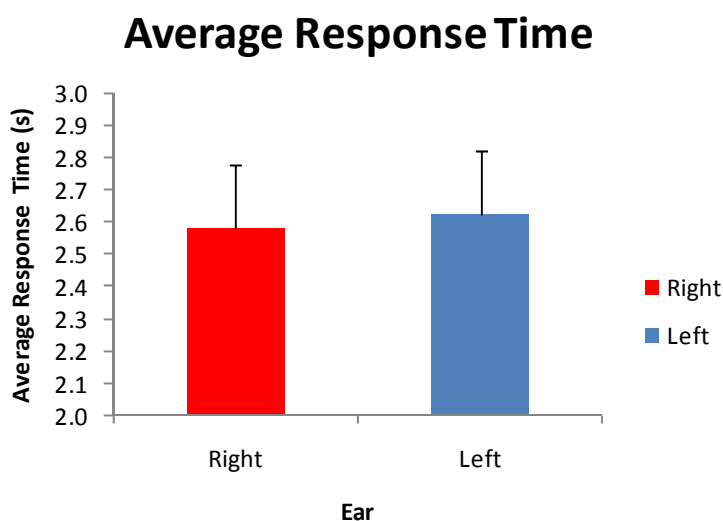


Figure 12: Comparison of mean response time (s) in the Auditory Manual mode for right and left ears.

3.9 Comparison of response time between ‘good’ performers and ‘poor’ performers.

Figure 13 illustrates the response times for ‘good performers’ (arbitrarily defined as those participants who scored $\geq 70\%$ in the AM mode) and ‘poor performers’ (those who scored $\leq 30\%$ correct). Again, this analysis was performed on data gathered from the 9-10 year age group from School 1, the largest cohort of participants ($n = 39$). Of the total, 30 participants were classified as either good ($n = 23$) or poor ($n = 7$) performers; the remaining 11 participants scored between 30-70%. The figure illustrates that the good performers took slightly longer to respond but as a group their response time showed less variability than the poor performers.

An independent samples t-test was conducted to compare the response time of these two groups. The t-test revealed no significant difference in the response time for good performers ($M = 2.48 \pm 1.16$) and poor performers ($M = 2.43 \pm 1.50$); $t(41) = 0.383$, $p = 0.447$.

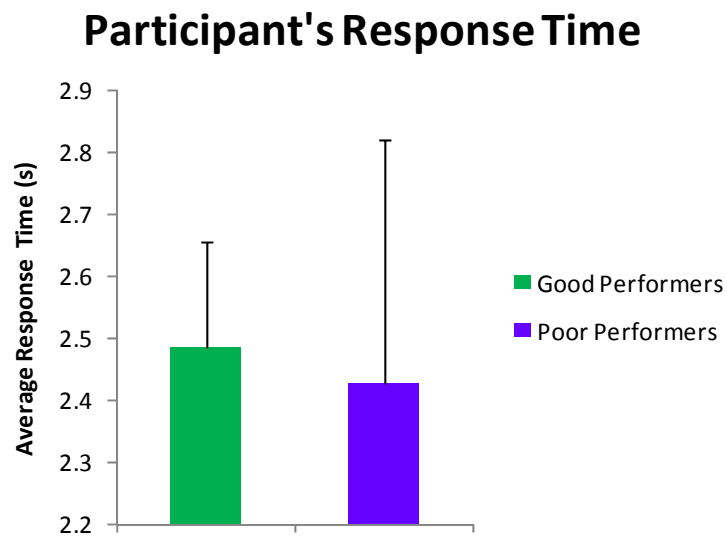


Figure 13: Comparison of response time for good and poor performers.

'Good Performers' = participants who scored $\geq 70\%$ correct and 'Poor Performers' = participants who scored $\leq 30\%$ correct. The results are from the 9-10 yr age group from School 1 in the Auditory Manual mode only.

3.10 Comparison between Schools – Visual mode

Figure 14 compares performance between schools for the Visual Manual and Visual Verbal modes. The graphs illustrate that all participants scored close to maximum in both modes.

A two-way ANOVA revealed a significant age effect [$F(2,122) = 7.482, p = <0.001$] between the three age groups. No school effect was found [$F(1,122) = 0.005, p = 0.944$] and there was no statistically significant interaction between the age group scores and School 1 and School 2 scores ($p = 0.358$).

The post hoc pairwise multiple comparisons (using the Holm-Sidak Method) revealed a significant difference between the 6 yr and both the 7-8 yr group ($p = 0.025$) and the 9-10 yr groups ($p = 0.017$).

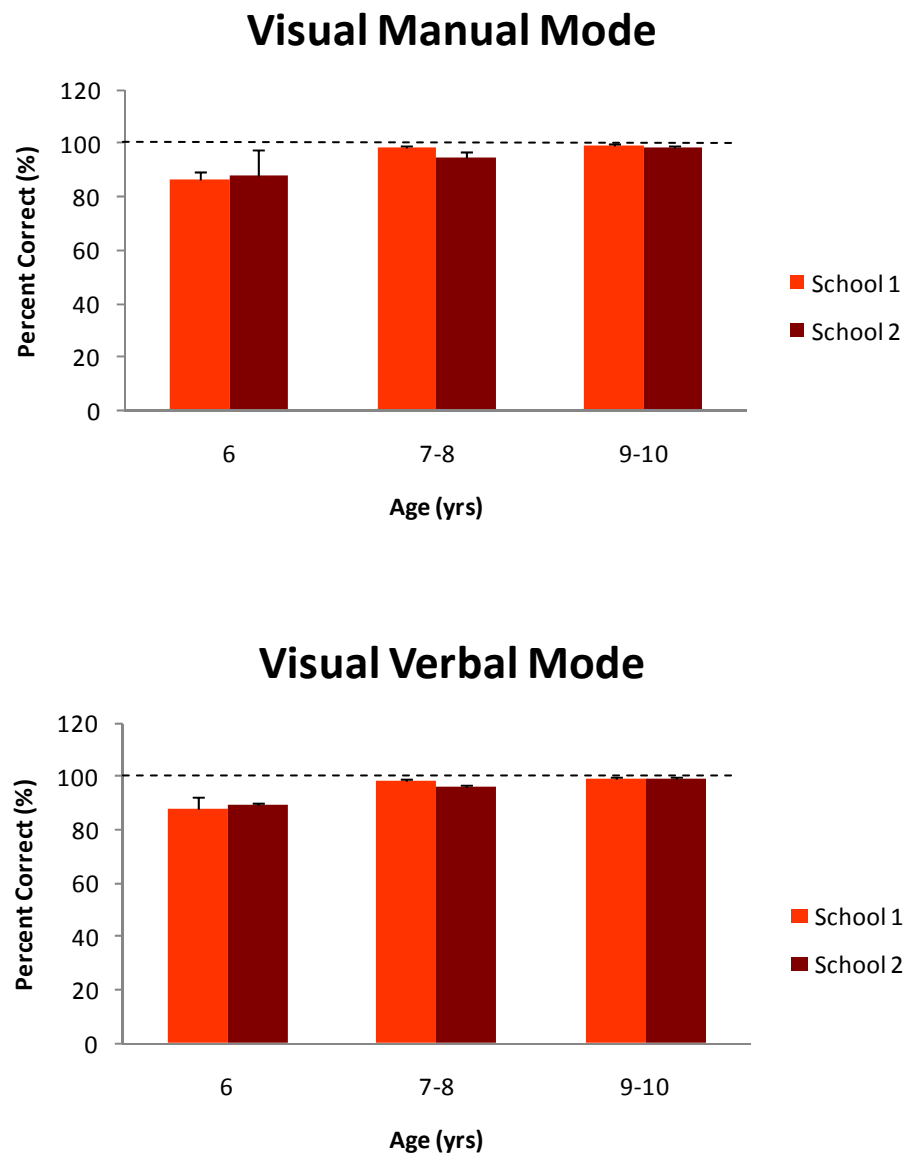


Figure 14: Comparison of Visual Manual and Visual Verbal scores between the mainstream schools.

The dashed line indicates the maximum possible score of 100% correct.

3.11 Comparisons to previously published normative data

In this section, results from the *Bird Song Game* are compared to previously published data (Kelly, 2007). Data from the AV mode only is compared because this response mode was most analogous to the administration format of the current, clinically used version of the FPT. In the AV mode, participants were required to give a verbal response after

listening to each stimulus triad. In the AM mode, in contrast, participants were required to enter responses via the touchscreen, a task which may utilise different cognitive processes than used in verbal reporting of tone sequences, although as shown in Figure 11, no significant difference in score according to response mode was found.

Table 5: Comparison of Auditory Verbal results to normative data.

The standard deviation is shown in parentheses.

	School 1		School 2		Normative Data	
Age	Right	Left	Right	Left	Right	Left
6	27.73 (24.84)	25.00 (25.30)	28.75 (32.92)	24.38 (27.05)	No data	No data
7-8	65.20 (30.40)	64.00 (32.15)	35.83 (24.88)	36.25 (25.29)	72.62 (18.85)	71.02 (19.43)
9-10	66.79 (28.04)	69.87 (26.19)	54.74 (34.74)	50.53 (33.87)	85.22 (8.38)	87.27 (8.37)

The results shown in Table 5 indicate that for both School 1 and 2 the mean scores were lower than those previously published. It should be highlighted that this data was collected from children in mainstream classrooms. Consequently, children with known learning or attentional difficulties were included in the cohorts presented here, and the mean values (and higher standard deviations) reflect this. Indeed, when the results from 5 children in the 9-10 year old age group from School 1 who were identified by the School's Special Needs Coordinator as having specific learning difficulties and/or Autism Spectrum Disorder were excluded from the calculation of mean score for this group, the mean for the remaining 'Typically Developing' children ($n = 34$) was comparable to that obtained by Kelly (2007); see Table 6 below.

Table 6: Typically Developing (TD) children in the 9-10 year age group form School 1, compared to normative data (Kelly, 2007).

Age Group	Typically Developing children (n = 34)	Normative Data
9-10	85.16 ± 16.09	86.25 ± 8.38

3.12 The Effects of Musical Experience on Performance

In order to investigate whether or not musical experience was reflected in better performance in the AM mode of The Bird Song Game, a comparison of mean scores were compared for those children with and without musical experience. These results are displayed in Figure 15.

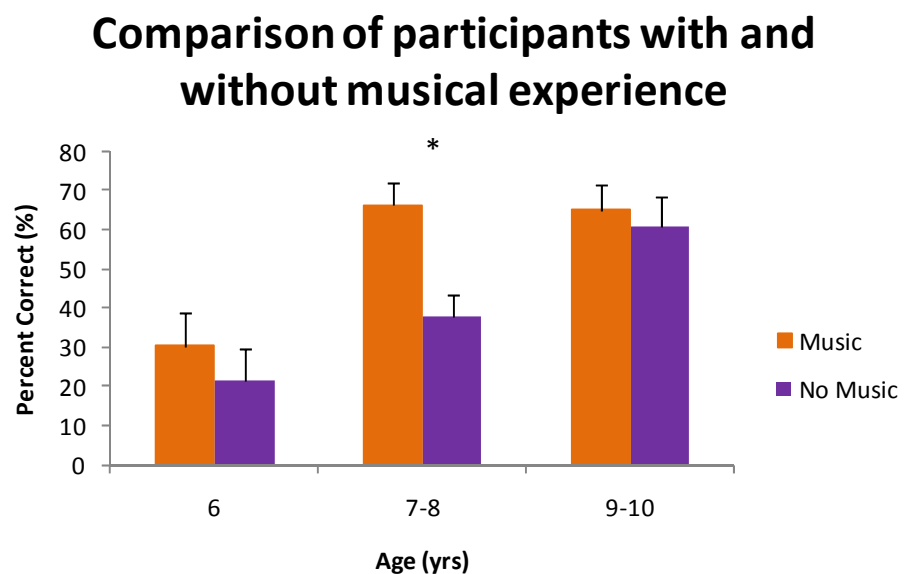


Figure 15: Mean score (Auditory Manual mode only) for participants with and without musical experience in each of the three age groups for both Schools.

A three-way ANOVA and post hoc pairwise comparisons (using the Holm-Sidak Method) revealed a significant difference between those children with musical experience and those without in the 7-8 year old group only.

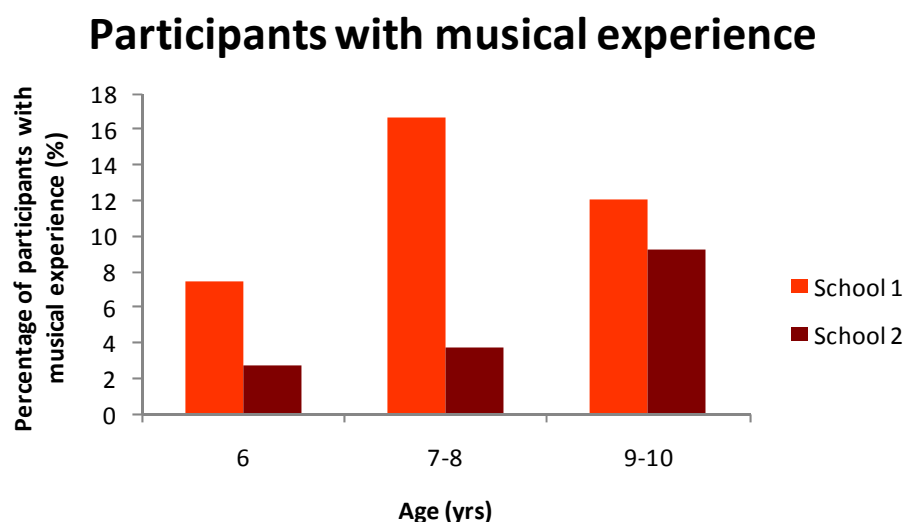


Figure 16: Summary of the number of participants with musical experience across each of the three age groups for both Schools

3.13 APD Group Participants

A group of children who had been previously diagnosed with APD through the University of Canterbury Speech and Hearing Clinic were recruited to participate in the second part of the study.

Participants' scores on the Frequency Pattern Test (FPT) and the Bird Song Game were compared. Results for each participant in the APD group ($n = 11$) are summarised in Table 7, which shows the right and left ear scores for the FPT, the *Bird Song Game*-AM mode and the *Bird Song Game*-VM mode. Participants 4 and 11 failed the FPT in the left ear only, passing in the right ear. The remaining 9 participants failed the FPT in both ears. In general the scores are similar across the two test platforms. There were some differences: participant 5 performed more poorly on the *Bird Song Game* compared to the FPT; participant 11 performed better on the *Bird Song Game* compared to the FPT. However, using the pass/fail criteria for the current FPT, a similar pattern of results was

found for the *Bird Song Game*-AM mode as was found for the FPT. That is, 9 participants failed in both ears, and participant 4 failed in the left ear only. The only altered result was for participant 11, who failed the FPT in the left ear only but passed the *Bird Song Game*-AM mode in both ears.

Table 7: Comparison of scores for the Frequency Pattern Test, the *Bird Song Game* - Auditory Manual mode and the *Bird Song Game* - Visual Manual mode for all participants in the APD group. Scores in bold font are 'pass' scores according to current NZ normative data (Kelly, 2007); others are 'fail' scores.

Participant	Score on Frequency Pattern Test (% correct)		Score on The Bird Song Game (% correct)		
			AM Mode		VM Mode
	Right Ear	Left Ear	Right Ear	Left Ear	
1	15	15	0	0	60
2	inconsistent	inconsistent	15	30	10
3	10	10	35	30	95
4	40	25	40	30	100
5	55	55	15	15	90
6	20	10	20	25	80
7	15	15	5	10	90
8	20	30	20	10	90
9	15	35	15	25	90
10	10	10	10	10	80
11	40	25	80	65	100

A comparison of the AM and AV scores was also undertaken to see if the finding observed in the MS group was also seen in the APD group; that is, that there would be no difference between the two modes of testing (Figure 17). A two-way ANOVA found no significant age effect [$F(1,40) = 3.423, p = 0.072$] or mode effect [$F(1,40) = 0.331, p = 0.568$] and there was no statistically significant interaction between the age group scores and the manual and verbal reporting mode scores ($p = 0.900$).

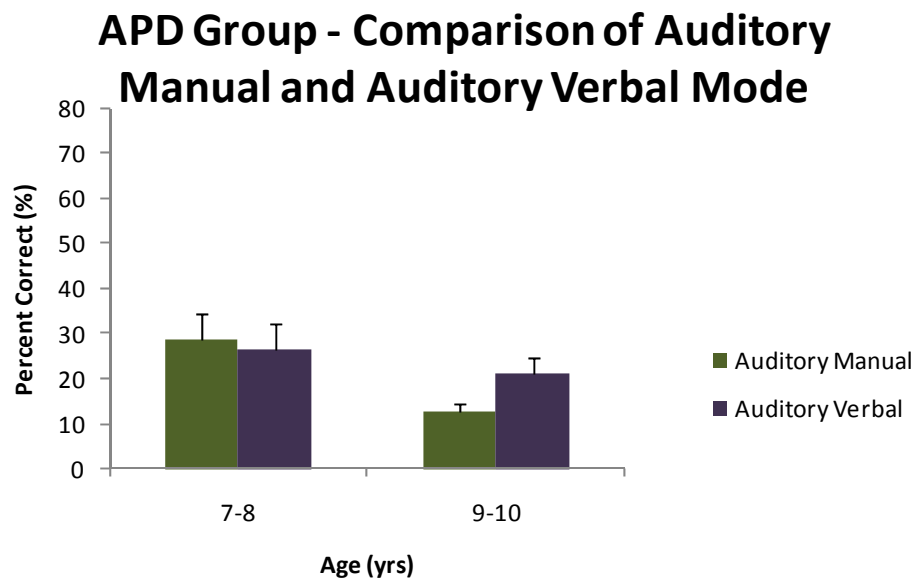


Figure 17: Comparison of Auditory Manual and Auditory Verbal scores in the APD Group

The performance (% correct) of the APD group is significantly poorer than that of the MS group (compare Figure 17 above to Figure 11); however there was no significant difference between the two reporting modes in the APD group, consistent with the finding in the MS group.

A similar comparison was made using visual modality data (see Figure 18) and once again no significant differences were found between the two modes of testing. The results of the two-way ANOVA revealed no significant age effect age effect [$F(1,18) = 0.178, p = 0.678$] or mode effect [$F(1,18) = 0.372, p = 0.550$] and there was no statistically significant interaction between the age group scores and the response mode ($p = 0.468$).

APD group - Comparison of Visual Manual and Visual Verbal Mode

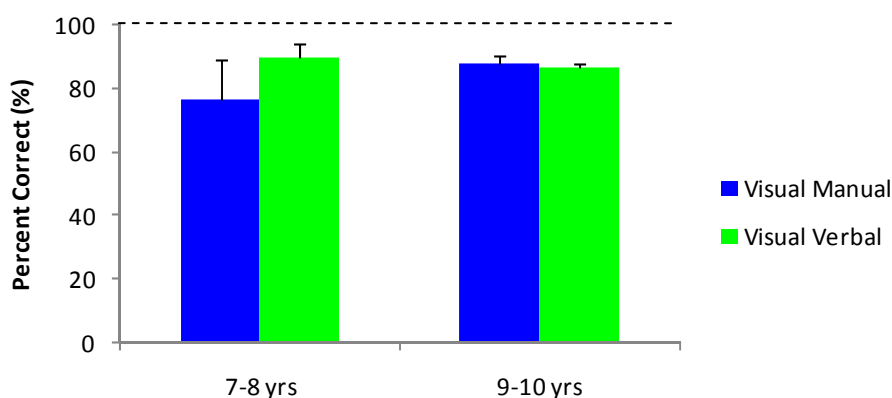


Figure 18: A comparison of Visual Manual and Visual Verbal scores in the APD Group.

The performance (% correct) of children with APD in the Visual Manual and Visual Verbal modes was better than their performance in either auditory mode (see Figure 17 above) but was not equivalent to that shown by the Mainstream School children in equivalent age groups (i.e. 7-8 and 9-10 year old groups).

A further comparison was made in order to ascertain whether or not the APD group performed significantly poorer on the Visual Manual mode compared to MS group. A t-test revealed a significant difference between mean scores for the 9-10 year old APD group ($M=87.5 \pm 5.00$) and the 9-10 year old MS group ($M=96.9 \pm 8.55$); $t(43)= 946.0$, $p = <0.001$.

3.14 Comparison of Scores between Groups and Across Studies

Finally, Figure 19 presents summary data, illustrating the mean percent correct scores for the APD group ($n = 11$), the 9-10 year old Main Stream School children from School 1 ($n = 39$), the 9-10 year old Typically Developing children from School 1 ($n = 34$) and the previously published normative data from 9-10 yr children ($n = 56$).

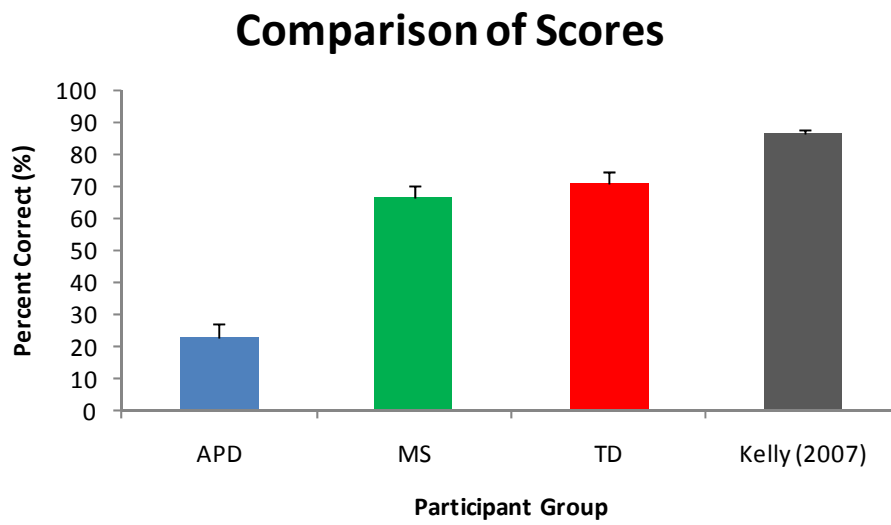


Figure 19: Comparison of scores between the APD group (APD), the Mainstream group (MS), the Typically Developing group (TD) and the Kelly (2007) data.

4 Discussion

This study used a newly developed computerised version of the Frequency Pattern Test (University of Canterbury *Bird Song Game*) to trial on Mainstream School children from two individual schools within the Christchurch area. The *Bird Song Game* was trialled on 128 Mainstream School children and 11 children diagnosed with APD through the University of Canterbury Speech and Hearing Clinic. The *Bird Song Game* consisted of the following four modes of testing: Auditory Manual (AM), Auditory Verbal (AV), Visual Manual (VM) and Visual Verbal (VV). Analysis of results included comparisons between age, gender, left and right ears and school. Further analysis was carried out to compare results between the manual and verbal mode of reporting responses as well as the auditory and visual modalities. In addition, a comparison was made with normative data for the current version of the Frequency Pattern Test (FPT). Each of these analyses will be discussed in turn below.

4.1 Effect of age and gender on auditory sequencing ability

In order to assess the effect of age and gender on auditory sequencing ability as assessed by the *Bird Song Game* a comparison of performance in the AM and AV mode for each age group and school was undertaken (refer to Figure 6). The results indicate that there was a general improvement in mean score with increasing age in both the AM and AV modes across both schools. This is consistent with the literature that states that humans are capable of discriminating intensity, frequency, and temporal cues from a young age (Hall & Grose, 1994; Jensen & Neff, 1993) and these abilities continue to improve into adulthood (Thompson, et al., 1999). In particular pitch discrimination requires the

maturation of peripheral and central auditory neural structures and pathways as well as the development of higher level cognitive skills such as attention and short term memory (Werner, 1996). Maturation depends on the degree of myelination of the structures that make up the central auditory nervous system (CANS). The formation of myelin facilitates the transmission of nerve impulses throughout the CANS, occurring in the brainstem first and not reaching higher cortical areas such as the corpus callosum until early adulthood (Johnson, Earnworth, Pinkston, Bigler, & Blatter, 1994; Pujol, Vendrell, Junqué, Martí Vilalta, & Capdevila, 1993).

Pitch and temporal discrimination abilities are also reliant on consistent stimulation of auditory pathways. Animal studies have shown that a lack of stimulation causes a disruption of neural firing which results in an inconsistent representation of the acoustic signal in the auditory brainstem structures (Gold & Knudsen, 2000). This may explain why some children who have a significant history of OME are at greater risk of developing APD than those who do not.

As mentioned above the development of higher level cognitive skills such as attention and short term memory have a considerable impact on pitch discrimination (Fry & Hale, 2000; Just & Carpenter, 1992; Jutras & Gagne, 1999) Performance on a pitch sequencing task such as the *Bird Song Game* may therefore be expected to improve as these abilities improve. Short term memory is known to improve with age (Just & Carpenter, 1992) and this may reflect some of the maturational effects seen in the present study (see Figure 6). Children from both schools showed an overall gradual increase in performance between the ages of 6-10 yrs. There was no statistically significant difference between boys and girls. This maturational effect is consistent with improvements in the ability to perceive

changes in auditory stimuli over time and the ability to process acoustic information to improve detection, recognition, and discrimination of stimuli (Just & Carpenter, 1992).

These skills are all necessary for good performance on the *Bird Song Game*.

4.2 **Comparison between schools of different decile rating**

It was hypothesised that children from a higher socioeconomic area would outperform their peers from poorer socioeconomic areas. Within New Zealand socioeconomic status is reflected in a school's decile rating, which is calculated from information obtained from the most recent census (Ministry of Education, 2009). The five factors that make up the socioeconomic indicator include household income, occupation, household crowding, education qualifications and income support (Ministry of Education, 2009). Each school is given a decile rating on a scale of 1 to 10, where 1 indicates a low socioeconomic status and 10 is an indication of high socioeconomic status.

The above hypothesis was supported by the results of this study. Participants aged 7-10 years of age from School 1 (decile 9) scored consistently higher in both the Auditory Manual and Auditory Verbal modes of testing compared to their peers from School 2 (decile 4) (refer to Figure 7 and 8). This study was limited in scope to just two schools, making it difficult to draw firm conclusions about the impact of socioeconomic status on performance on the *Bird Song Game*; however the findings are certainly suggestive of an association between these variables. Good performance on the Bird Song Game presumably relies on several underlying skills including temporal processing abilities and pitch perception. The influence of socioeconomic status on these skills and possible reasons for the difference in performance between the two schools will be considered below.

One putative risk factor for the development of APD is a past history of otitis media with effusion (OME), a condition causing temporary conductive hearing loss that is especially prevalent in early childhood (Plack, 2010). Studies in both animals and children (Gravel et al., 2006; Moore, et al., 2003; Zumach, et al., 2010) demonstrate that chronic OME can lead to disruptions in the temporal aspects of sound transmission through the auditory system. OME is a common childhood problem throughout the world, but particularly among indigenous populations, including Māori (Coates, Morris, Leach, & Couzos, 2002; Giles & O'Brien, 1989). Although a detailed investigation of the ethnicity of participants was not undertaken in this study, there were a higher proportion of Māori and Pacific Island children in School 2 (Carol Coleman (School 1) and Marianne Langton (School 2), personal communication). If a higher incidence of OME exists among participants from School 2 compared to those from School 1, and OME puts children at greater risk for APD, then it may be that the poorer results on the *Bird Song Game* for School 2 participants reflects this higher incidence. Further investigation is required to follow up on this possibility. Future research exploring the link between OME and APD incidence in indigenous populations and the relationship between OME and decile rating would add important information to our current understanding of the nature of auditory processing deficits in school aged children.

A further possible explanation for the poorer performance of School 2 participants on the *Bird Song Game* may be a higher incidence of learning difficulties among this group.

Learning difficulties such as SLI and SRD have been shown to coexist with APD (Sharma, et al., 2009). Furthermore, there is a substantial amount of literature supporting a causal relationship between temporal processing deficits and SLI and SRD (Tallal, 2004; Wible, et al., 2002, 2005). In addition, a strong family history of language and reading difficulties is

commonly reported in children who present with learning difficulties of their own (Bishop, 2001; Hayiou-Thomas, 2008). A detailed analysis of the incidence of learning difficulties among participants and their parents was beyond the scope of the present study. However, future research is needed to examine the relationship between familial learning difficulties, decile rating (an indicator of socioeconomic factors including household income and level of education) and the incidence of temporal processing deficits. This data would help to establish whether children attending lower decile schools are at higher risk of auditory processing difficulties and other learning difficulties.

4.3 **Left and right ear differences**

To ascertain whether or not there was difference in performance between the ears, indicating a possible right ear advantage, a comparison of scores from individual ears was made (refer to Figure 9 and 10). The results from the present study indicate that there was no difference in performance between the ears, indicating the lack of a significant right ear advantage in any age group, from either school, for either the AM or AV mode.

The right ear advantage (REA) typically occurs in tests where dichotic speech stimulation is used or in tasks that significantly challenge the auditory system (Kimura, 1961a, 1961b).

Kimura's *structural pathway model* of dichotic listening postulates that acoustic information is replicated in both the ipsilateral and contralateral auditory pathways, but because the contralateral pathways are stronger and more numerous, they inhibit the ipsilateral pathways when competing signals or challenging tasks are presented. This results in a REA for many listening tasks, since the destination of the contralateral pathways from the right ear is the left hemisphere – dominant for speech processing in most people. Information from the left ear, on the other hand, presumably has to travel a

longer course, from the right hemisphere to the language-dominant left hemisphere, across the corpus callosum. In the case of the FPT the perception and verbal labelling of the acoustic pattern requires processing by both hemispheres of the brain (Musiek, Pinheiro, & Wilson, 1980), since in most people the right hemisphere is responsible for processing pitch information while the left is responsible for linguistically labelling the response. According to the structural pathways model, in which afferent signal travel time is the key factor underlying dichotic asymmetries, a *left* ear advantage may be expected on the FPT. That is, information from the right ear presumably has to travel to the left hemisphere, across to the right hemisphere via the corpus callosum for pitch processing, then back again to the left hemisphere for linguistic labelling. Information from the left ear, on the other hand, crosses the corpus callosum just once, from right to left. However, we did not find any such ear advantage in this study, in either mode (i.e. whether or not ‘linguistic labelling’ of the tone was required). Nor did we find any difference in response time for left and right ears. It cannot be said that this was due to the task not being sufficiently challenging to elicit an ear advantage if one existed: even in children for whom the task was clearly challenging (e.g. the youngest age group, or children with APD), no right or left ear asymmetry was noted. The monaural nature of the task removed any ‘competition’ between ipsilateral and contralateral pathways during stimulus presentation, so it may be that the task was not sufficiently sensitive to the underlying characteristics of the afferent pathways, and that any ‘neural travel time’ differences were not sufficiently large to manifest in response time or accuracy. Alternatively, it may be that the structural pathways model, a bottom-up interpretation of asymmetries in challenging listening tasks, may not be sufficient to account for all

auditory processing phenomena, and that a model incorporating top-down supramodal spatial deficits or preferences may be more appropriate. (Cacace & McFarland, 2009).

4.4 **Mode differences**

It was hypothesised that there would be no significant difference between manual and verbal reporting modes in children with or without APD. The present study supported this hypothesis. We found no difference between the Auditory Verbal and Auditory Manual mean scores from either the Mainstream group (AM – 51.1%, AV – 52.0%) or the APD group (AM – 22.7%, AV – 24.5%) (Refer to Figure 11) Also, no significant difference was found in the mean score for the visual modality, in the Mainstream group (VM – 96.4%, VV – 96.5%), or the APD group (VM – 80.5%, VV – 88.2%). Since results in both modes have produced very similar results it would suggest that the manual and verbal reporting modes require comparable degrees of cortical processing and therefore the difficulty these children have on the current FPT is unlikely to be attributed to difficulties with the linguistic labelling of the tones, i.e. accessing the appropriate linguistic labels from the left hemisphere. If this was the case the performance for the verbal reporting mode would be expected to be significantly poorer than on the manual reporting mode where no linguistic labelling was required (akin to allowing participants to use their hands to respond in a clinical setting).

Moreover, the difficulty the APD group had with the AM or AV mode does not appear to result from a general sequencing, task demand or memory issue, since most of these children performed at a similar level as the Mainstream group on the visual sequencing tasks (see section 4.9 below). This suggests that these children have specific difficulty sequencing, either manually or verbally, a series of acoustic stimuli. Since there was no

difference in performance between the two modes, this suggests that the contribution of linguistic labelling factors to performance is minimal at best.

Given that we found no difference between the two modes of testing, our results suggest that performance on an auditory sequential patterning task depends far more on age and other factors than on mode of response, at least in the participant cohorts included here.

As a consequence of this finding it would suggest that when the *Bird Song Game* is administered a manual response could be used with equal validity to a verbal response.

Although this mode of reporting does not appear to improve performance on the FPT, it also does not affect it negatively, and is therefore a possible alternative. However, inclusion of both modes of response in a standard assessment may yield valuable information about the impact of linguistic labelling factors in individual children, or in specific populations (e.g. dyslexic children), so may be a useful component in future applications.

4.5 Response time

In order to evaluate the time required to respond to the triads of tones presented in the AM mode, we measured the time of each individual response for all the participants in the 9-10 year age group. Figure 12 illustrates these results and shows that the response time for right ($M=2.66 \pm 1.37$) and left ears ($M=2.65 \pm 1.27$) was not significantly different.

To further evaluate response time we analysed the results of the 'good performers' compared to the 'poor performers' and found that although the good performers took slightly longer to respond, as a group their response time showed less variability than the poor performers.

While no difference in response time between the left and right ears was found, it is significant to note that with this computer based version of the test, additional data such as response time can be effortlessly measured. In future studies where different auditory stimuli are presented to different populations of participants, response time may become an important parameter to measure.

4.6 **Modality specificity Tasks**

It was hypothesised that performance on auditory sequencing tasks will be significantly poorer than on visual sequencing tasks in children with or without APD. This hypothesis was supported by the data. The performance of both the MS group and the APD group was significantly better on the visual sequencing tasks compared to the auditory sequencing tasks (compare Figures 11 and 14, for example). This modality difference was particularly large in the APD group who scored $M = 22.7 \pm 19.6$ on the AM mode compared to $M = 87.5 \pm 5$ on the VM mode (9-10 year old children). This reflects the fact that the APD group had significantly greater difficulty than the MS group in the auditory sequencing task, but for the most part, their performance on the visual sequencing task was comparable with the MS group. While their performance on the visual sequencing task was substantially better than their performance on the auditory task, there was a small but significant difference between the two groups, with the APD group performing more poorly on the visual sequencing task than the MS group. However, when individual scores are considered, rather than the average score for the group, it is apparent that some children in the APD group scored very highly on the VM mode (7 of the 11 participants scored above 90%) while others scored very poorly. This suggests that for most of the children in the APD group, their difficulty with auditory sequencing was

modality specific, and not a general sequencing difficulty; whereas for others, this may not be the case. This is discussed further in section 4.9 below.

This is an important issue to address. Cacace & McFarland (2005) have argued that the use of auditory-only testing, although necessary, does not distinguish cognitive, language or attention problems from APD. They propose the incorporation of multimodal testing in an attempt to identify an auditory specific deficit that is not influenced by these other factors, a proposition supported by ASHA (2005). A typical APD test battery, however, does not include multi-modal tests, therefore fails to differentiate between auditory specific deficits and non-auditory specific factors such as attention, fatigue, motivation and memory (Jerger & Musiek, 2000). By incorporating a parallel visual processing task, such as the one utilised in the *Bird Song Game*, into a standard APD assessment, it may be possible to identify children who perform poorly on sequential pattern tasks in both the visual and auditory modalities. If this was the case, it may be suggestive of a more global or amodal deficit, as opposed to an auditory specific perceptual difficulty with recognition of acoustic contours. This type of distinction may impact significantly on the management and recommendations made for the individual.

The *Bird Song Game* application has been designed to include a visual correlate of the auditory sequencing task used in the current FPT. Although it cannot be said that the visual and auditory sequencing tasks incorporated into the *Bird Song Game* are entirely analogous, given the difficulty in comparing tasks in two sensory modalities which operate in fundamentally different ways, they are at least equivalent in many respects. We have held constant as many factors as possible: visual and auditory stimuli are presented with identical duration and interstimulus intervals, the test interface and

environment remains identical across both modalities, and the method of test administration and participant response is held constant. In addition, we have endeavoured to minimise the effects of non-auditory factors such as attention, fatigue and motivation by providing engaging computer animations and an interactive computer touch screen interface. This along with the encouragement provided by the examiner should reduce the effects of these factors in a clinical setting. We envisage that compared to the current CD based version of the FPT, the *Bird Song Game* will provide increased motivation for the task, helping to maintain the individual's attention and reduce fatigue; thereby producing a more robust clinical tool for the differential diagnosis of APD in children.

4.7 Comparison to normative data

The data from the Mainstream group collected in this study showed a significantly poorer performance when compared to the current NZ norms for the FPT (Kelly, 2007) (refer to Table 5 and 6). However, it should be noted that in this study, participants were recruited from mainstream classrooms and all children in a class were included in the data set. This inclusive approach was not seen as a disadvantage in this study as the focus of the study was the test platform itself, but it is likely that given the reported incidence of APD, some MS group children may well have had APD or other learning difficulties. Indeed, some children in this study scored as low as 10% correct in the auditory mode of testing whereas others scored 100%. This demonstrates that within a typical mainstream classroom performance on this task varies widely. By including all children in the cohort, the mean scores in each age group were lower and the spread of data was larger when

compared to studies where only children with no history of learning or listening difficulties were included.

When children with identified learning difficulties were removed from the calculations (see Table 6), our mean scores were similar to the current normative data (Kelly, 2007). Thus the Bird Song Game produces similar results and as a consequence could be utilised in a clinical setting to replace the current FPT, with the added advantages of being more engaging for children and inclusion of a visual sequencing task.

4.8 **The influence of musical experience**

It was hypothesised that the performance of children with musical experience will be significantly higher than that of children with no musical experience. This hypothesis was partly supported by our results.

Participants from School 2 showed a poorer performance on the *Bird Song Game* than their peers in School 1 (refer to Figure 15). This may reflect a deficit in frequency patterning abilities from this cohort of children. It has been reported that children with musical experience perform better in tasks involving pitch perception than do children with no musical experience (Magne, et al., 2006). Researchers suggest that this improved pitch perception ability is likely to affect the reception and production of speech, a task that is reliant on good temporal processing. In this study we found that a higher proportion of children from School 1 received musical tuition (36.1%) compared to those from School 2 (15.7%), although the overall number was relatively low from both schools (refer to figure 16). However, a statistically significant relationship between musical experience and performance on the test was found in the 7-8 yr old children (refer to Figure 15). Importantly, this was the age group for which the difference between the two

schools was most marked – it may be that early musical education provides children with an advantage when it comes to tasks dependent on pitch and/or temporal processes, but that by 9-10 years of age, this advantage is minimised. Another possible explanation may be that the relatively small number of participants in this study with musical education was insufficient to detect a significant effect across all age groups. It would be useful in future research to compare larger cohorts of children with and without musical education to explore the relationship between musical experience and the development of temporal processing skills.

4.9 **Children with APD**

The current study has demonstrated that the *Bird Song Game*, a computer-based auditory and visual sequential pattern task, was capable of discriminating between children with and without APD. Comparisons with normative data from the current FPT indicate the equivalency of the Auditory Manual mode of reporting to the current FPT. The results demonstrate that the *Bird Song Game* is a potentially useful addition to a clinical APD test battery.

The extent to which extra-auditory factors influence performance on APD tests is a major source of controversy in the field (McFarland & Cacace, 2009), yet the current test battery makes no attempt to determine the modality specificity of a child's presenting difficulties. A visual sequencing task has therefore been incorporated into the *Bird Song Game*, and may help to identify children who perform poorly on sequential pattern tasks in both visual and auditory modalities (e.g. Participants 1 and 2 in the APD group), suggestive of a more global, working memory deficit or multimodal sequencing difficulty, as opposed to an auditory specific perceptual difficulty with recognition of acoustic contours. This type

of distinction may impact significantly on the management recommendations made by relevant health professionals regarding the learning environment of a given child.

The computer-based design of the *Bird Song Game* has several advantages over the current CD based version of the FPT. Firstly, the software scores the participant's responses automatically, and also records timing information in the Manual response modes. This helps to eliminate tester error, and allows for additional analysis of timing data. Moreover, by inclusion of a conditioning phase, confusion about the vocabulary used to describe pitch is removed from the interpretation of results. Finally, a further advantage of the computer-based Bird Song Game is that acoustic parameters such as rate, contrast and complexity can be easily adjusted to allow for future investigations regarding the influence of these parameters on performance on an auditory sequencing task.

Computerized and interactive test methods are more engaging for a child, and also minimise the fatigue and loss of attention problematic in APD testing, which by nature tends to be lengthy, repetitive and not particularly child-friendly. Many of the tests used in a typical APD test battery were originally designed for use in adults, and when applied to the paediatric population, the non-interactive nature of the tests, the lack of meaningful feedback or reward for participants, combined with the length of time it typically takes to perform a full assessment (up to 3 hours) can mean that test results are tainted by fatigue, wavering attention and lack of motivation. It is a clinical challenge, therefore, to distinguish those children for whom the tasks are truly difficult from those children whose results are affected by lack of interest or motivation in the tests, resulting in a risk of misclassification or overdiagnosis of children with APD (Silman, et al., 2000).

This is particularly problematic for the large number of children with attention difficulties in addition to their listening difficulties. The Bird Song Game, in addition to providing information about the modality specificity of a processing deficit, is also a more engaging and interactive test and it is envisaged that it will help clinicians to maintain a child's interest and attention during testing (although this was not specifically examined in the current study).

4.10 Theoretical and Clinical Implications

The current study has demonstrated that the *Bird Song Game*, a computer-based auditory and visual sequential pattern task, was capable of discriminating between children with and without APD. Comparisons with normative data from the current FPT indicate the equivalency of the AM mode of reporting to the current FPT. The results demonstrate that the *Bird Song Game* is a potentially useful addition to a clinical APD test battery.

The extent to which extra-auditory factors influence performance on APD tests is a major source of controversy in the field (McFarland & Cacace, 2009), yet the current test battery makes no attempt to determine the modality specificity of a child's presenting difficulties. A visual sequencing task has therefore been incorporated into the *Bird Song Game*, and may help to identify children who perform poorly on sequential pattern tasks in both visual and auditory modalities (e.g. Participants 1 and 2 in the APD group), suggestive of a more global, working memory deficit or multimodal sequencing difficulty, as opposed to an auditory specific perceptual difficulty with recognition of acoustic contours. This type of distinction may impact significantly on the management recommendations made by relevant health professionals regarding the learning environment of a given child.

The computer-based design of the *Bird Song Game* has several advantages over the current CD based version of the FPT. Firstly, the software scores the participant's responses automatically, and also records timing information in the Manual response modes. This helps to eliminate tester error, and allows for additional analysis of timing data. Moreover, by inclusion of a conditioning phase, confusion about the vocabulary used to describe pitch is removed from the interpretation of results. Finally, a further advantage of the computer-based Bird Song Game is that acoustic parameters such as rate, contrast and complexity can be easily adjusted to allow for future investigations regarding the influence of these parameters on performance on an auditory sequencing task.

Computerized and interactive test methods are more engaging for a child, and also minimise the fatigue and loss of attention problematic in APD testing, which by nature tends to be lengthy, repetitive and not particularly child-friendly. Many of the tests used in a typical APD test battery were originally designed for use in adults, and when applied to the paediatric population, the non-interactive nature of the tests, the lack of meaningful feedback or reward for participants, combined with the length of time it typically takes to perform a full assessment (up to 3 hours) can mean that test results are tainted by fatigue, wavering attention and lack of motivation. It is a clinical challenge, therefore, to distinguish those children for whom the tasks are truly difficult from those children whose results are affected by lack of interest or motivation in the tests, resulting in a risk of misclassification or overdiagnosis of children with APD (Silman, et al., 2000). This is particularly problematic for the large number of children with attention difficulties in addition to their listening difficulties. The Bird Song Game, in addition to providing information about the modality specificity of a processing deficit, is also a more engaging

and interactive test and it is envisaged that it will help clinicians to maintain a child's interest and attention during testing (although this was not specifically examined in the current study).

4.11 Limitations and Directions for Future Research

This study has clearly illustrated the potential of the *Bird Song Game*, an interactive computer-based auditory and visual sequential pattern task, as a clinically useful tool for the assessment of APD in school aged children. A group of typically developing children showed similar level of performance on *The Bird Song Game* as was found in New Zealand school children tested using the FPT(Kelly, 2007), illustrating the equivalence of the two platforms in the auditory modality. However, the study was not without its limitations. Two schools (of decile 9 and 4) were involved in this study, and while a comparison of scores on the Bird Song Game revealed a significant difference between the two schools, it is not possible to make generalised statements about the impact of decile rating on performance on auditory sequencing tasks based on this small number of schools. It may well be that the particular cohort of participants differed significantly from one another for reasons unrelated to decile. The finding does make it clear that an important future research direction is to further explore the influence of socioeconomic factors on the development of auditory skills, and the impact of these skills on language and literacy acquisition. Which of the various factors that contribute to the decile rating are relevant, if any; and what is the role of early musical education on a child's developing auditory processing skills, particularly temporal processing skills? We hypothesised that performance would be significantly higher for children with musical experience compared to children with no musical experience. We found some support for this hypothesis in the

7-8 year old group, but not in the other age groups. It may be that the relatively small number of participants in this study with musical education was insufficient to detect a significant effect across all age groups. It would be useful in future research to compare larger cohorts of children with and without musical education to explore the relationship between musical experience and the development of temporal processing skills. If a link exists between musical experience and auditory temporal processing skills, should primary schools be encouraged to invest in musical education in the early grades? Clearly to answer these questions, larger scale, multidisciplinary studies involving a wide cross-section of the community are needed.

A further limitation of this study relates to the degree of equivalency of both the auditory and visual task. In designing these tasks every attempt was made to maintain the consistency of parameters used in both modalities: the duration of the stimulus presentation, the interstimulus interval, the animation itself and the position of the animation on the screen were identical for both the auditory and visual task. However, similar to other studies (Bellis, et al., 2008) we were unable to establish whether or not the tasks were truly analogous. Further investigation is required to determine this and to ascertain whether the inclusion of visual analogs to central auditory tests adds appreciably to the differential diagnosis of APD from other more global deficits. It should be pointed out, however, that perhaps trying to achieve truly analogous tasks is not the central point of including visual modality tests in an APD test battery, and in fact may not be achievable, given the very different neurological nature of the auditory and visual systems. Rather the goal is to identify those children who have a multimodal or amodal deficit from those that have a 'purely' auditory deficit. Provided the fundamental task demands are equivalent across the two tests (e.g. in this case, the correct sequencing of 3

successively presented stimuli) then that goal should be achievable, despite inevitable differences in sensitivity and underlying processes.

The computer-based platform of the *Bird Song Game* allows for the modification of parameters to assess auditory and visual sequential pattern identification abilities of children. To illustrate one example of this; previous studies have shown that children diagnosed with APD show improved performance on auditory sequencing tasks if there is greater contrast or complexity of the auditory stimuli (Tallal, et al., 1996). The platform utilised in this study allows for the easy manipulation of these parameters. Further research in this direction may go some way toward identifying the precise nature of the auditory processing deficits in these children.

This study has provided evidence that an interactive computer based test has several advantages over its CD based counterpart. It also provides a catalyst for future research into the inclusion of multimodal testing in an APD test battery designed specifically for children. Further research on the clinical utility of the *Bird Song Game* and other computer based APD tests will offer an important tool to assist in the differential diagnosis of APD and other more global difficulties.

Appendices

Appendix I: Ethical Approval

Ref: HEC 2010/24

31 March 2010

Caroline Smales
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Caroline

The Human Ethics Committee advises that your research proposal "Computer-based assessment of auditory processing disorders in school aged children: a pilot study" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 29 March 2010.

Best wishes for your project.

Yours sincerely

Dr Michael Grimshaw
Chair, Human Ethics Committee

Appendix II: Project Information Sheet for Teachers

University of Canterbury

Department of Communication Disorders



TEACHER INFORMATION SHEET A

FOR THE RESEARCH STUDY

Computer-based assessment of auditory processing disorders in school aged children: a pilot study

TEACHER INFORMATION

The children in your class are invited to participate in the research project *Computer-based assessment of auditory processing disorders in school aged children: a pilot study*.

AIM OF PROJECT

The aim of this project is to develop a computer-based version of a test called the *Frequency Pattern Test* used in auditory processing assessments and to trial this on typically developing school-aged children.

PROCEDURES

The children's involvement in this project will involve one session of approximately 40 minutes, held at your school. **The children will be required to leave their regular classroom for approximately 40 minutes at a time that is deemed most appropriate by you, their teacher.** The following is an outline of the tasks required of each child:

Screening Audiometry:

A standard hearing screening test will determine a child's eligibility for the study. This involves monitoring a child's response to stimuli presented at specific intensities. The child is asked to press a button each time they hear a tone, presented over headphones.

Time required: 10 minutes.

Tympanometry:

Children will undergo screening tympanometric testing. A soft probe is inserted into the ear canal and a low level sound is presented in the presence of variable air pressure. The amount of reflected sound pressure gives a measure of eardrum mobility.

Time required: 2-5 minutes.

Frequency Patterns Test:

The computer-based version of the Frequency Patterns Test, called "The Birdsong Game" uses a touch screen as the response interface. The primary investigator will be seated at a laptop computer in a quiet room, and the participant will be seated in front of a touch screen in the same room as the investigator. The investigator will provide verbal instructions and encouragement to the participant throughout the test session. The following data will be collected:

1. Visual and Auditory mode: An initial instruction screen familiarises participants with the stimuli (tones produced by six animated birds arranged in two rows of three) and the task required of them. They then proceed to the conditioning screen, where a visual stimulus (animation) will be paired with an auditory stimulus (tone) in a sequence. Participants are then asked to touch the images on the screen in the same sequence.
2. Auditory-Manual mode: The participants hear tonal stimuli only, and are rewarded with a visual stimulus only after they have made their response (touched the screen). A total of 20 presentations of each of the 6 possible combinations of tone triads will be presented and response data will be collected in XML (Extensible Markup Language) format.
3. Auditory-Verbal mode: The participants are now asked to refrain from touching the screen, but instead must verbally describe the sequence of tones they hear using their own descriptive vocabulary as established in the instruction screen. The clinician presses

the touchscreen in the sequence reported by the participant, and the data from 20 presentations per participant is collected as above.

4. Visual-Manual mode: Participants receive visual stimuli only in this test, and are required to press the touch screen in the correct sequence (20 presentations).

5. Visual-Verbal mode: As in (iii) the participants are asked not to touch the screen, but to use their own vocabulary to describe the sequence of visual stimuli.

Time required: 20 minutes.

POSSIBLE RISKS

As with any testing that requires attentiveness, it is possible that some children will experience a degree of stress. In order to minimize this, each child will receive encouragement and he/she will be provided with a small reward upon the completion of testing. Their parents have been invited to accompany their child during testing to provide them with emotional support and encouragement. Testing will be discontinued, should any child feel distressed during testing.

At the completion of testing a report containing results of the hearing test and recommendations for follow-up, if required, will be sent home with each child.

ELIGIBILITY FOR THE PROJECT

In order for the children to participate in this project, they must (i) have normal audiometric thresholds (determined by hearing screening); (ii) be 6-11 years of age.

WITHDRAWAL & CONFIDENTIALITY

Each individual child has the right to withdraw from the project at any time, including withdrawal of any information provided. Please note that withdrawal of participation will not affect any on-going or future services with the University of Canterbury.

The results of the project may be published, but each child is assured of the complete confidentiality of data gathered in this investigation. The identity of the children will not

be made public without their consent. Also, a summary of results will be available at your request, on completion of this study

In order to ensure confidentiality, the information gathered will be assigned a code number and all identifiable information removed. Data will be kept in a locked filing cabinet within a lockable room in the Department of Communication Disorders for a period of 10 years, after which time it will be destroyed.

The project is being carried out as a requirement for a Masters of Audiology by Caroline Smales, under the supervision of Dr. Natalie Rickard, who can be contacted at the University of Canterbury on +64 3 364 3052. We will be pleased to discuss any concerns you may have about participation in the project.

The project has been reviewed **and approved** by the University of Canterbury Human Ethics Committee.

ACKNOWLEDGEMENTS

We would like to thank The Neurological Foundation of New Zealand and the Maurice and Phyllis Paykel Trust for providing the funding for this project.

Caroline Smales
Masters of Audiology Student
Department of Communications Disorders
University of Canterbury
Private Bag 4800
Christchurch, New Zealand
Email: cjs169@student.canterbury.ac.nz

Appendix III: School Participation Consent Form

University of Canterbury

Department of Communication Disorders



School Consent Form

Computer-based assessment of auditory processing disorders in school aged children: a pilot study

Research Student: Caroline Smales

Supervisor: Dr. Natalie Rickard

Co-supervisor: Dr. Greg O'Beirne

_____ School would like to acknowledge the approval for the above named research study to be conducted on its premises and with its students.

_____ School understands the purpose of this study is to develop a computer-based version of a test called the *Frequency Pattern Test* used in auditory processing assessments and to trial this on typically developing school-aged children.

_____ School has been provided with an information sheet outlining the details of the above named project, and the requirements of the teachers and students in this research study. Teachers from _____ School have read, and understood the requirements as described on the information sheet for the above named project.

I understand that the data obtained in this study may be published and that all identifying information and personal details will be removed from this data before this occurs.

NAME: _____

SIGNATURE: _____

DATED: _____

Appendix IV: Teacher Participation Consent Form**University of Canterbury****Department of Communication Disorders****Teacher Consent Form**

Computer-based assessment of auditory processing disorders in school aged children: a pilot study

Research Student: Caroline Smales

Supervisor: Dr. Natalie Rickard

The children in my class have been asked to participate in a research study to determine the effectiveness of a computer-based version of a test called the *Frequency Pattern Test* used in auditory processing assessments in school-aged children.

I have been provided with an information sheet outlining the details of the above named project, and the requirements of the children in this research study. I have read, and understood the requirements as described on the information sheet for the above-named project.

On this basis, I provide consent for the children to participate in this research project. I provide consent for the results of this research study to be published or presented publicly, provided each child's identity is kept confidential and anonymity is preserved.

I understand that each individual child is free to discontinue participation in this project, and I am free to withdraw my consent at any time, without prejudice against further care that they may receive at this institution. This includes the withdrawal of any information the children or myself have supplied.

The project has been reviewed **and approved** by the University of Canterbury Human Ethics Committee.

NAME OF PARENT: _____

NAME OF CHILD: _____

SIGNATURE OF TEACHER: _____

DATED: _____

Appendix V: Project Information Sheet for Parents

University of Canterbury

Department of Communication Disorders



PROJECT INFORMATION SHEET A

FOR THE RESEARCH STUDY

Computer-based assessment of auditory processing disorders in school aged children: a pilot study

PARENT INFORMATION

Your child is invited to participate in the research project *Computer-based assessment of auditory processing disorders in school aged children: a pilot study*.

AIM OF PROJECT

The aim of this project is to develop a computer-based version of a test called the *Frequency Pattern Test* used in auditory processing assessments and to trial this on typically developing school-aged children.

PROCEDURES

Your child's involvement in this project will involve one session of approximately 40 minutes, held at your child's school. **The children will be required to leave their regular classroom for approximately 40 minutes at a time that is deemed most appropriate by their teacher.** The following is an outline of the tasks required by your child:

Screening Audiometry:

A standard hearing screening test will determine a child's eligibility for the study. This involves monitoring a child's response to stimuli presented at specific intensities. The child is asked to press a button each time they hear a tone, presented over headphones.

Time required: 10 minutes.

Tympanometry:

Children will undergo screening tympanometric testing. A soft probe is inserted into the ear canal and a low level sound is presented in the presence of variable air pressure. The amount of reflected sound pressure gives a measure of eardrum mobility.

Time required: 2-5 minutes.

Frequency Patterns Test:

The computer-based version of the Frequency Patterns Test, called “The Birdsong Game” uses a touch screen as the response interface. The primary investigator will be seated at a laptop computer in a quiet room, and the participant will be seated in front of a touch screen in the same room as the investigator. The investigator will provide verbal instructions and encouragement to the participant throughout the test session. The following data will be collected:

1. Visual and Auditory mode: An initial instruction screen familiarises participants with the stimuli (tones produced by six animated birds arranged in two rows of three) and the task required of them. They then proceed to the conditioning screen, where a visual stimulus (animation) will be paired with an auditory stimulus (tone) in a sequence. Participants are then asked to touch the images on the screen in the same sequence.
2. Auditory-Manual mode: The participants hear tonal stimuli only, and are rewarded with a visual stimulus only after they have made their response (touched the screen). A total of 20 presentations of each of the 6 possible combinations of tone triads will be presented and response data will be collected in XML (Extensible Markup Language) format.
3. Auditory-Verbal mode: The participants are now asked to refrain from touching the screen, but instead must verbally describe the sequence of tones they hear using their own descriptive vocabulary as established in the instruction screen. The clinician presses the touchscreen in the sequence reported by the participant, and the data from 20 presentations per participant is collected as above.

4. Visual-Manual mode: Participants receive visual stimuli only in this test, and are required to press the touch screen in the correct sequence (20 presentations).

5. Visual-Verbal mode: As in (iii) the participants are asked not to touch the screen, but to use their own vocabulary to describe the sequence of visual stimuli.

Time required: 20 minutes.

Possible Risks

As with any testing that requires attentiveness, it is possible that your child will experience some stress. In order to minimize this, your child will receive encouragement and he/she will be provided with a small reward upon the completion of testing. You may also wish to be present during the testing to provide your child with emotional support and encouragement. Testing will be discontinued, should you or your child feel distressed at any time.

At the completion of testing a report containing results of the hearing test and recommendations for follow-up, if required, will be sent home with your child.

ELIGIBILITY FOR THE PROJECT

In order for your child to participate in this project, they must (i) have normal audiometric thresholds (determined by hearing screening); (ii) be 6-11 years of age.

WITHDRAWAL & CONFIDENTIALITY

Your child has the right to withdraw from the project at any time, including withdrawal of any information provided. Please note that withdrawal of participation will not affect any on-going or future services with the University of Canterbury.

The results of the project may be published, but your child is assured of the complete confidentiality of data gathered in this investigation. The identity of your child will not be made public without their consent. Also, a summary of results will be available at your request, on completion of this study

In order to ensure confidentiality, the information gathered will be assigned a code number and all identifiable information removed. Data will be kept in a locked filing cabinet within a lockable room in the Department of Communication Disorders for a period of 10 years, after which time it will be destroyed.

The project is being carried out as a requirement for a Masters of Audiology by Caroline Smales, under the supervision of Dr. Natalie Rickard, who can be contacted at the University of Canterbury on +64 3 364 3052. We will be pleased to discuss any concerns you may have about participation in the project.

The project has been reviewed **and approved** by the University of Canterbury Human Ethics Committee.

ACKNOWLEDGEMENTS

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Appendix VI: Parent Consent Form

University of Canterbury

Department of Communication Disorders



Parent Consent Form

Computer-based assessment of auditory processing disorders in school aged children: a pilot study

Research Student: Caroline Smales

Supervisor: Dr. Natalie Rickard

My child has been asked to participate in a research study to determine the effectiveness of a computer-based version of a test called the *Frequency Pattern Test* used in auditory processing assessments in school-aged children.

I have been provided with an information sheet outlining the details of the above named project, and the requirements of my child in this research study. I have read, and understood the requirements as described on the information sheet for the above-named project.

On this basis, I provide consent for my child to participate in this research project. I provide consent for the results of this research study to be published or presented publicly, provided my child's identity is kept confidential and anonymity is preserved.

I understand that my child is free to discontinue participation in this project, and I am free to withdraw my consent at any time, without prejudice against further care that they may receive at this institution. This includes the withdrawal of any information my child or myself have supplied.

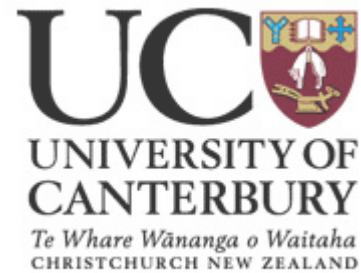
The project has been reviewed **and approved** by the University of Canterbury Human Ethics Committee.

NAME OF PARENT: _____

NAME OF CHILD: _____

SIGNATURE OF PARENT: _____

DATED: _____

Appendix VII: Hearing Test Results Summary**University of Canterbury****Department of Communication Disorders**

Hearing Test Results

Computer-based assessment of auditory processing disorders in school aged children: a pilot study

Today _____ completed a hearing screening test as part of his/her participation in the above research project.

Today's results indicate that _____ passed the hearing screening test.

No follow up is necessary however if you have any concerns in the future regarding your son's/daughter's hearing you may contact us at the following

Jacquie MacDonald (Clinic receptionist)

The University of Canterbury

Speech and Hearing Clinic

Phone: (03) 364-2408

jacquie.macdonald@canterbury.ac.nz

Thank you for taking part in this study.

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